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FINAL TECHNICAL REPORT

FIELD DEMONSTRATION OF THE HOT GAS DECONTAMINATION SYSTEM

Report No. SFIM-AEC-ET-CR-95011

Prepared for

The U.S. Army Environmental Center
Aberdeen Proving Ground, Maryland

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The Hot Gas Decontamination System (HGDS) is an innovative technology which utilizes low temperature heat (350°F) to decontaminate structures which have been operationally contaminated with chemical warfare agent. The field demonstration of the HGDS at Rocky Mountain Arsenal (RMA) Colorado, successfully proved the effectiveness of the Hot Gas technology for decontamination of structures (concrete and steel) contaminated with mustard agent. Sampling and analysis for agent after the field demonstration proved that the process had decontaminated the area to an analytically clean level.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACFM	Actual Cubic Feet per Minute
AE	Agent element
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BCO	Battelle Columbus Operations
BHP	Brake Horsepower
BQL	Below Quantification Limit
BTU	British Thermal Units
°C	Degrees Centigrade
CASARM	Chemical Agent Surety Analytical Reference Material
CCV	Continuing calibration verification
CDH	Colorado Department of Health
CEM	Continuous emission monitoring
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Chain of Custody
CO_2	carbon dioxide
CO	carbon monoxide
cplg	coupling
DA	Department of the Army
DAS	Data Acquisition System
dba	decibels (A scale)
DIL	Demolish, Incinerate and Landfill
DOD	Department of Defense
EPA	Environmental Protection Agency
°F	Degrees Fahrenheit
FAR	Federal Acquisition Regulations
FID	Flame Ionization Detector
FPD	Flame Photometric Detector
g, gm	gram
GC	Gas Chromatograph

HC	Hydrocarbon
H or HD	Mustard or Distilled Mustard
HEPA	High efficiency particulate air
HGD	Hot Gas Decontamination
HGDS	Hot Gas Decontamination System
HP	Horsepower
Hr.	Hour
ICP-AES	Inductively coupled plasma atomic emission spectrometry
ID	Induced Draft
I/O	Input/Output
KVA	Kilovolt amps
m	milli
MCC	Motor Control Center
MCP	Main Control Panel
mg	milligrams
Mhz	Megahertz
Minicams	Miniaturized Chemical Agent Monitoring System
mL	milliliter
MQL	Minimum Quantification Level
MS	Mass Spectrometer
MSSS	Minicams stack sampling systems
NDIR	Nondispersive Infrared
NIST	National Institute of Standards and Technology
NO_x	nitrogen oxides
NPT	National Pipe Thread
NRT	Near Real Time
OD	Outside Diameter
OSHA	Occupational Safety and Health Administration
O_2	oxygen
PAH	Polynuclear Aromatic Hydrocarbons
Pam	Pamphlet
PCS	Process control system
PLC	Programmable Logic Controller

PNL	Pacific Northwest Laboratories
PMRMA	Program Manager Rocky Mountain Arsenal
PPE	Personal Protective Equipment
psig	pounds per square inch gauge pressure
QA	Quality Assurance
QAM	Quality Assurance Manager
QC	Quality Control
RCM	Resident Construction Manager
RMA	Rocky Mountain Arsenal
RMA AAL	Rocky Mountain Arsenal Analytical Agent Laboratory
SARMS	Standard Analytical Reference Materials
SCFM	Standard Cubic Feet per Minute
SO_2	sulfur dioxide
SVR	Source Verification Report
TVA	Tennessee Valley Authority
TWA	Time Weighted Average
UPS	Uninterruptible Power Supply
USAEC	U.S. Army Environmental Center
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
μ	micro
μg	microgram
μL	microliter
WG	Water Gauge
XDS	Exempt Dilute Solution

1.0 EXECUTIVE SUMMARY

The Hot Gas Decontamination System (HGDS) is an innovative technology which utilizes low temperature heat (350 °F) to decontaminate structures which have been operationally contaminated with chemical warfare agent. The field demonstration of the HGDS at Rocky Mountain Arsenal (RMA) Colorado, successfully proved the effectiveness of the Hot Gas technology for decontamination of structures (concrete and steel) contaminated with mustard agent. Sampling and analysis for agent after the field demonstration proved that the process had decontaminated the area to an analytically clean level.

The Hot Gas decontamination process was the most effective of several methods investigated in the laboratory by the U.S. Army Environmental Center (USAEC) for decontaminating structural materials contaminated with a chemical warfare agent. Following an evaluation of a number of potential test sites, the Mustard Thaw Pit in Building 537 at RMA was selected for the field demonstration of the HGDS.

The objective was to demonstrate that the hot gas technology is a viable technology to decontaminate chemical agent-contaminated concrete and metal structures and equipment.

The HGDS used a gas burner, similar to a building furnace, to heat the target area. Furnace heat was directed to the mustard pit, which was covered with a primary containment barrier and surrounded by a secondary containment to contain any volatilized chemical agent. In the heated state, the chemical agent which had been operationally absorbed in the pit structure was volatilized and released inside the pit. Also, some of the agent was thermally degraded *in situ*.

A fume burner with dual burners was the primary treatment system used to destroy the toxic components of the vapor released from the pit. The pit exhaust gas was pulled through the fume burner chamber by two induced draft (ID) fans. The pit, secondary containment and entire HGDS system were maintained under negative pressure by the ID fans, to prevent release of contaminants to the environment. The ID fans delivered the treated exhaust gas to a stack for release to the atmosphere. Ventilation air from the secondary containment was treated in a carbon filter bank, and injected into the fume burner exhaust (along with outside air), for cooling purposes. A backup treatment system consisted of a radiator and carbon filter to provide exhaust gas treatment in the event of fume burner failure.

The field demonstration met the operational criteria for volatilization and destruction of the mustard agent in the concrete pit, and destruction of the mustard in the process exhaust gas. The field demonstration proved that the Hot Gas process can be effectively applied to operationally contaminated structures and equipment in a manner that protects worker and public health and safety, and promotes environmental protection. The secondary containment, primary containment, and negative pressure system proved effective in controlling volatilized off-gases from the process.

A cost comparison of the HGDS to the only alternative technology (demolish and incinerate) indicated that the cost of the Hot Gas process is approximately half of the estimated $10.4 million cost of this alternative. In addition, the Hot Gas technology is projected to be a safer operation, and does not require the amount of non-standard construction methods as the alternate technology.

2.0 INTRODUCTION AND SCOPE

This Technical Report documents the design, construction, and operation of the Field Demonstration of the Hot Gas Decontamination System (HGDS) at Rocky Mountain Arsenal, CO. The HGDS is an innovative technology which utilizes low temperature heat to decontaminate structures and equipment which have been operationally contaminated with chemical warfare agent. This report presents results and conclusions from the performance of the field demonstration. Lessons learned and recommendations for future projects are presented. A project cost and cost comparison to the primary alternative technology are included in Section 7.

2.1 OBJECTIVE AND SCOPE

The objective of the field demonstration of the HGDS was to demonstrate that the Hot Gas technology can be successfully used to decontaminate structures (concrete and steel) and equipment which have been operationally contaminated with chemical agent. The structure selected for the demonstration, the Mustard Thaw Pit in Building 537, was contaminated with mustard (H or HD) during loading and unloading of mustard containers. The pit contained contaminated tanks and pipes, in addition to contaminated concrete in the floor and walls.

A secondary objective was to prove that the Hot Gas technology is a viable alternative to demolition and incineration, the only method of decontaminating structures and equipment. This method (demolish and incinerate) is very expensive and presents a considerable health and safety risk. A major advantage of the Hot Gas technology as an alternative to "demolish and incinerate" is the potential for future reuse of structures after decontamination.

2.2 BACKGROUND

The U.S. Army owns facilities, including buildings and large equipment, used in the manufacture, processing, loading, storage, and destruction of chemical warfare agents. As part of its responsibilities in the Department of Defense (DOD) real property disposal, the USAEC must identify, contain, and eliminate toxic and hazardous materials at facilities that are declared excess. With this mandate, the USAEC must provide the technical basis to implement decontamination, and ensure that decontamination is effective.

Only one method is currently approved for decontaminating materials for release from government control. This method is thermal treatment at a uniform temperature of 1,000 °F for 15 minutes. Materials exposed to such conditions are described as having attained "5X" rating status and are defined as suitable for unrestricted use (DA Reg and Pam 385-61). The "5X" rating is an operational scenario based on time and temperature exposure, and is not an analytically proven standard. Structures must be demolished and incinerated to meet this requirement, and demolition must be performed under controlled ventilation according to Army regulation (DA Reg and Pam 385-61). The demolish and incinerate method is very expensive and poses a considerable health and safety risk. The Hot Gas technology is intended to reduce cost and minimize health and safety risk.

Many facilities contaminated with chemical agents are structurally sound, and it is desirable to decontaminate them without damage to their structural integrity. Free from chemical agent contamination, these facilities could be reused, mothballed, or made excess.

The USAEC has investigated several methods in the laboratory for decontaminating structures contaminated with a chemical warfare agent. The Hot Gas process was the most effective of the methods tried in the laboratory. It was then demonstrated successfully in a controlled pilot evaluation performed at Dugway Proving Ground, UT, using agent-spiked samples.

A site selection report was prepared in September 1988, which evaluated 13 sites for potential application of the Hot Gas technology. The site selection process evaluated institutional, informational, chemical, and engineering criteria. From 13 sites evaluated, the Mustard Thaw Pit in Building 537 at Rocky Mountain Arsenal was selected for the field demonstration. The Mustard Thaw Pit is below the first floor and behind the north wall in Building 537. Building 537 is in the northwestern quadrant of Section 1 in the South Plant's manufacturing complex. The building was formerly a distilled mustard (HD) manufacturing and demilitarization facility, and is contained in the area where mustard agent was manufactured in the 1940s and demilitarized in the mid-1970s. The Mustard Thaw Pit in Building 537 was selected based upon the pit's size and shape, relatively well-known historical use, and the existence of mustard and mustard breakdown products.

The mustard pit is a sub-basement (15 ft. 7 in. wide by 50 ft. 8 in. long and 9 ft. 3 in. deep) with concrete floors and walls. A plan and section of the mustard pit are shown in Figure 2.1, illustrating its geometric configuration. Three tanks were left in the mustard pit during the field demonstration to test the effectiveness of the HGDS for decontaminating process equipment. Two 2,600-gallon steel tanks are horizontal cylindrical tanks and are 19 feet long and 5 feet in diameter. A small condensate tank is a 250 gallon horizontal cylindrical tank, 5 feet long and 3 feet in diameter.

Building 537 was constructed in 1945 as part of the crude mustard distillation plant where mustard (H) was purified to produce HD, a product of high stability for munitions use. At a later time, the building was used for unloading of ton containers and transfer of mustard to demilitarization furnaces in Building 538. Building 537 was used for at least six projects involving mustard production and demilitarization. Contamination of the mustard pit occurred during this period due to spills, leaks or tank overfills as the result of mustard transfer operations. The original floor was covered over with new concrete pours at least twice, to encapsulate former mustard contamination.

Mustard (H) is a blister agent which is used primarily for causality effect. The chemical formula for H is $Cl\text{-}CH_2\text{-}S\text{-}CH_2\text{-}S\text{-}CH_2\text{-}CH_2\text{-}Cl$. It has a volatility of 610 mg/m^3 at 20 °C and 75 mg/m^3 at 0 °C. The worker permissible exposure limit is 0.003 mg/m^3, which registers as 1.0 unit Time Weighted Average (TWA) on the Minicams agent monitors. Mustard hydrolyzes slowly with water to form dithiane and oxathiane, both of which have uncharacterized toxicity. Mustard thermally decomposes at 149-177 °C (300-350 °F).

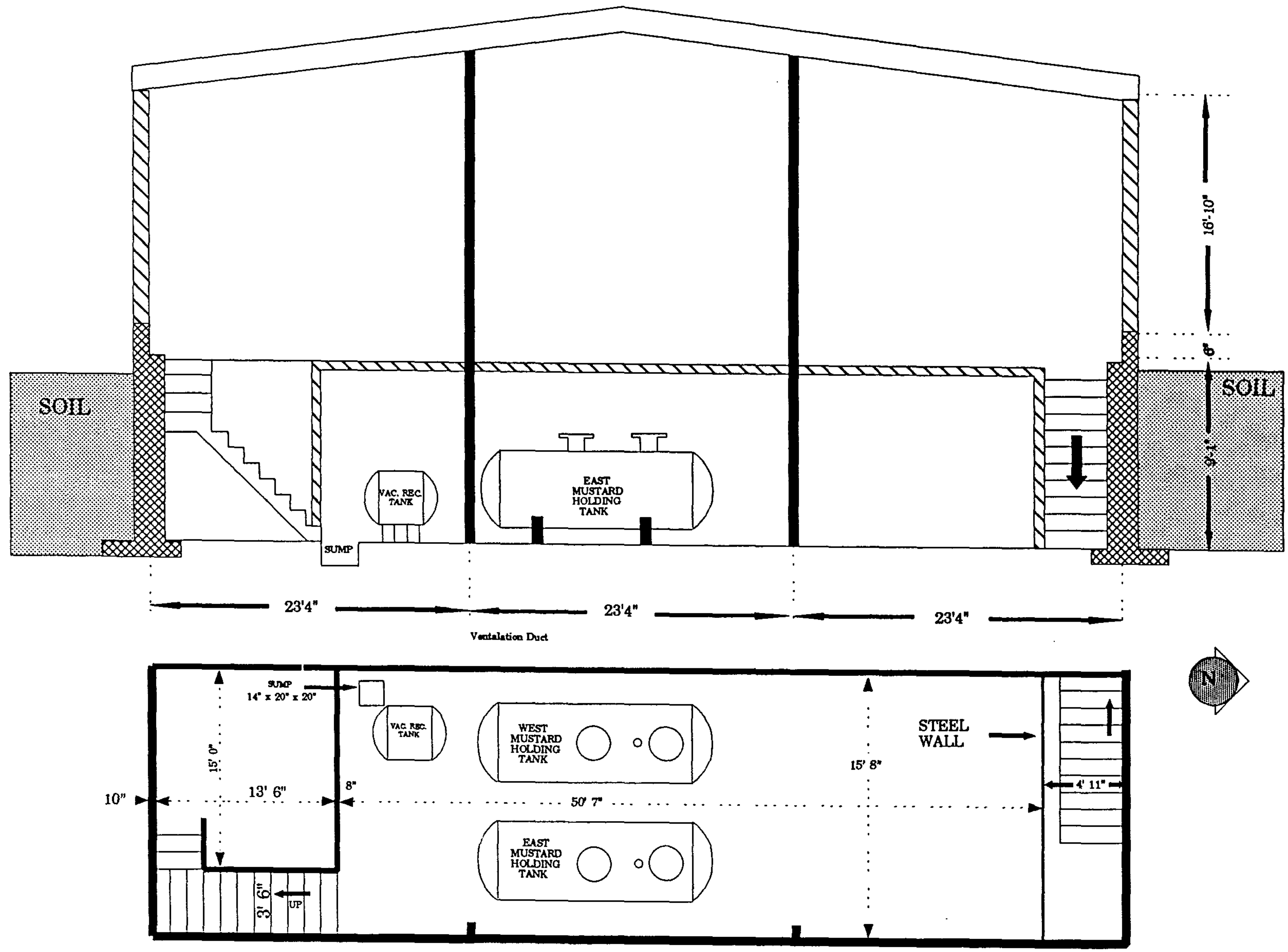


Figure 2.1 Mustard Pit Plan and Section

3.0 PROCESS DESCRIPTION AND DESIGN CONSIDERATIONS

3.1 PROCESS DESCRIPTION SUMMARY

The HGDS was designed to decontaminate structures which have been contaminated with volatile organic chemical agent. Hot burner exhaust gas was distributed into the contaminated structure to volatilize and break down contaminants. Primary and secondary containments surrounded the structure to contain the off-gas and provide additional safety. The volatilized contaminants were then directed to a fume burner treatment system and destroyed under operating conditions of 2,000 °F and 2 seconds residence time. The structure and containments were maintained under negative pressure by induced draft (ID) fans, which directed the treated exhaust to a stack. A backup treatment system consisted of a radiator to reduce exhaust gas temperature and carbon filter train to remove any hazardous materials from the exhaust gas. The instrumentation, controls, and stack monitoring system were designed for maximum safety and environmental protection.

The HGDS used a hot gas burner, similar to a building furnace, to heat the target area. Hot exhaust gas from the main burner was directed to the mustard pit, which was covered with a primary containment barrier and surrounded by a secondary containment. In the heated state, the chemical agent impregnated in the pit structure was volatilized and released inside the pit. Also, some of the agent was thermally degraded *in situ*.

A fume burner with dual burners was the primary treatment system to destroy toxic vapors released from the pit. The pit exhaust gas was pulled through the fume burner chamber by the ID fans. Toxic components of the exhaust gas were destroyed in the fume burner. The pit and entire HGDS were maintained under negative pressure by the ID fans located in the exhaust system, to prevent release of contaminants to the environment. The ID fans delivered the treated exhaust gas to a stack for release to the atmosphere. Ventilation air from the secondary containment was treated in a carbon filter bank, and injected into the fume burner exhaust (along with outside air), for cooling purposes. The backup treatment system (radiator and carbon filter) provided exhaust gas treatment in the event of fume burner failure. The

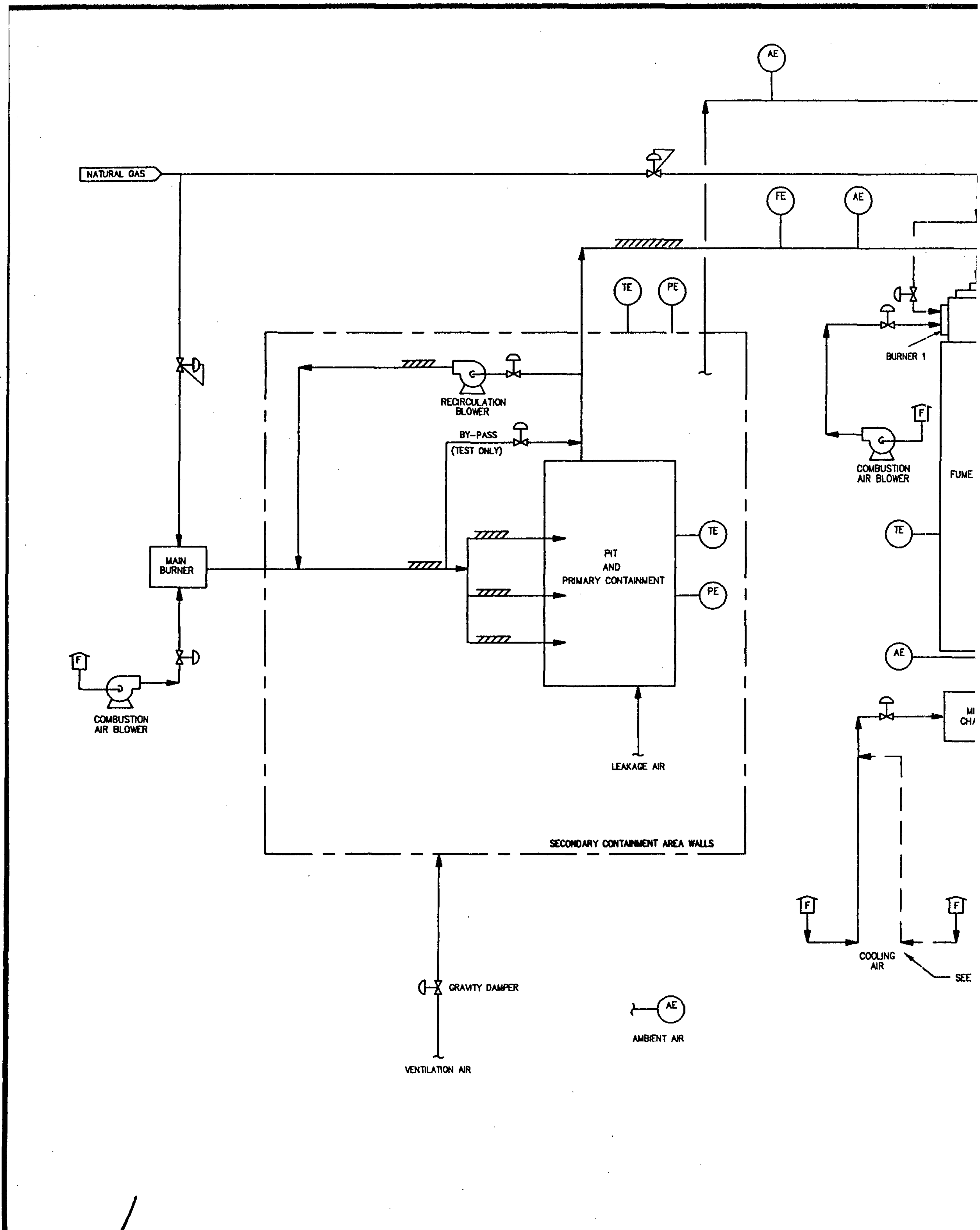
Process Flow Diagram for the HGDS is presented in Figure 3.1, and identifies the process and major equipment items. Also, the General Arrangement Plan for the HGDS is presented in Figure 3.2. Photographs of the mustard pit, the site, process equipment, and control screens are presented in Figure 3.3a-j.

The HGDS design criteria included a significant level of health, safety, and environmental provisions to safeguard the public and workers. This applied to pre-construction activities, construction, and operation. Redundant ID fans at the system exhaust maintained the system negative pressure. The system pressure was monitored with electronic pressure transducers and pressure gauges. The key control and monitoring points were backed up for safety purposes. The system had two backup electrical power supplies to maintain power and system ventilation.

Real-time chemical agent monitors (Minicams) were located at key locations throughout the system to provide insurance of safety, effectiveness, and environmental protection. A Minicam located at the fume burner exhaust provided monitoring of the treated pit exhaust for system efficiency. A Minicam located on the discharge stack provided monitoring of the discharge to the atmosphere. Several other Minicams were located throughout the system.

An instrumentation and control system provided safe, efficient operation of the HGDS. The control system monitored variations in the temperature heatup rate and concentration of agent in the process gas during heatup. Pressure, temperature, and agent monitors were located throughout the HGDS and provided data signals to the Data Acquisition System (DAS) located in the control trailer. HGDS operators monitored the control and DAS system at this location. The control trailer housed both the control system and the DAS.

The control system had interlocks that allowed for conditional automatic shutdowns, such as main burner shutdown in the event of fume burner failure. Process, instrumentation, and control systems which have critical importance with regard to health, safety, or environmental protection were provided with redundant systems. A slow heatup of the pit promoted gradual volatilization of organics within the pit. Unburned hydrocarbons were monitored at the inlet



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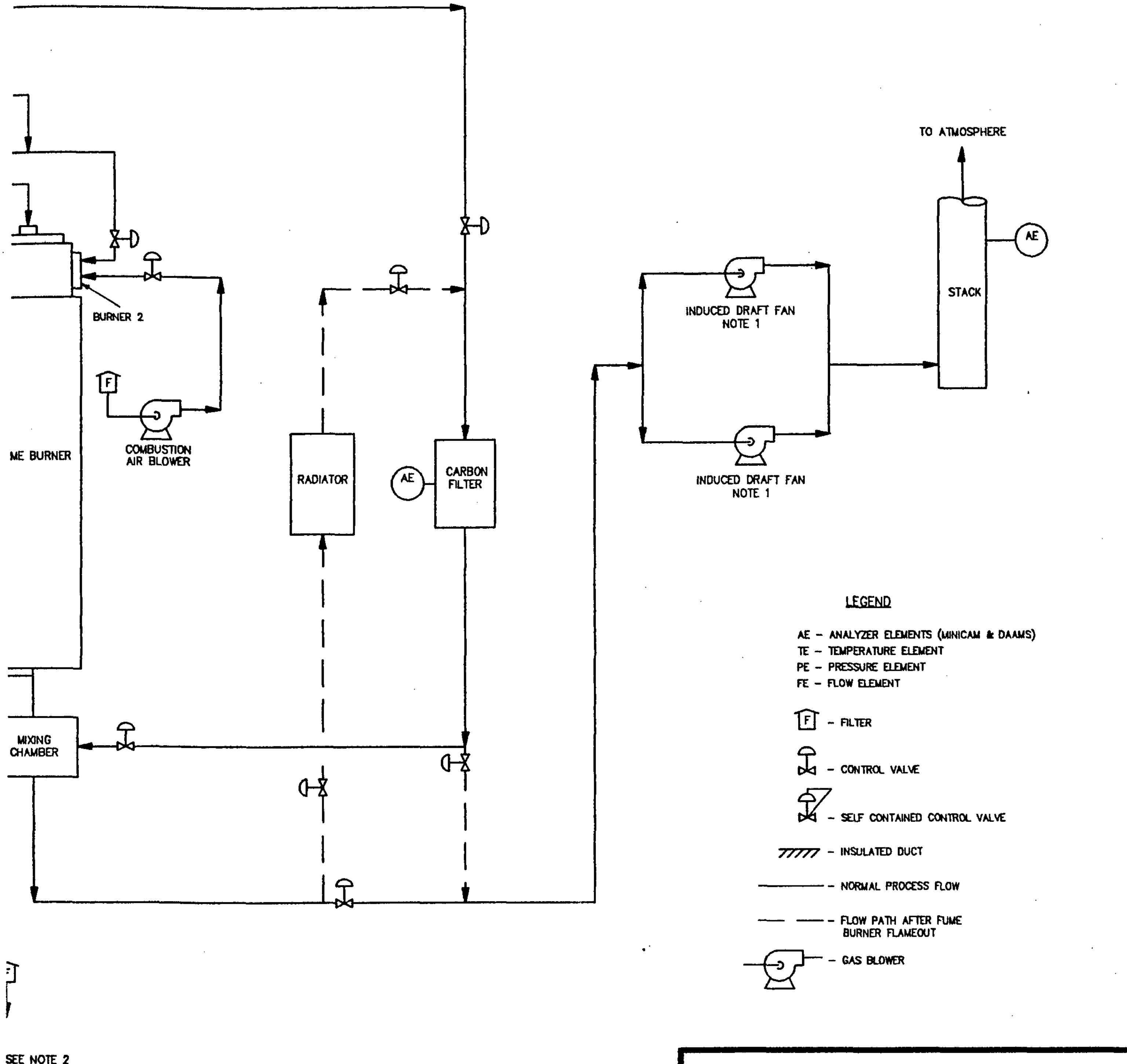


NOTES:

1. BLOWER NORMALLY OPERATES AT ONE HALF CAPACITY. WHEN ONE BLOWER BECOMES INOPERATIVE THE REMAINING BLOWER OPERATES AT FULL CAPACITY.
2. TWO STREAMS ARE SHOWN FOR CLARITY. THE ACTUAL PIPING SYSTEM WILL INCORPORATE ONLY A SINGLE PIPE WITH A MODULATING CONTROL VALVE WHICH CAN FLOW EITHER OR BOTH VOLUMES AS THE OPERATING CONDITION REQUIRES.

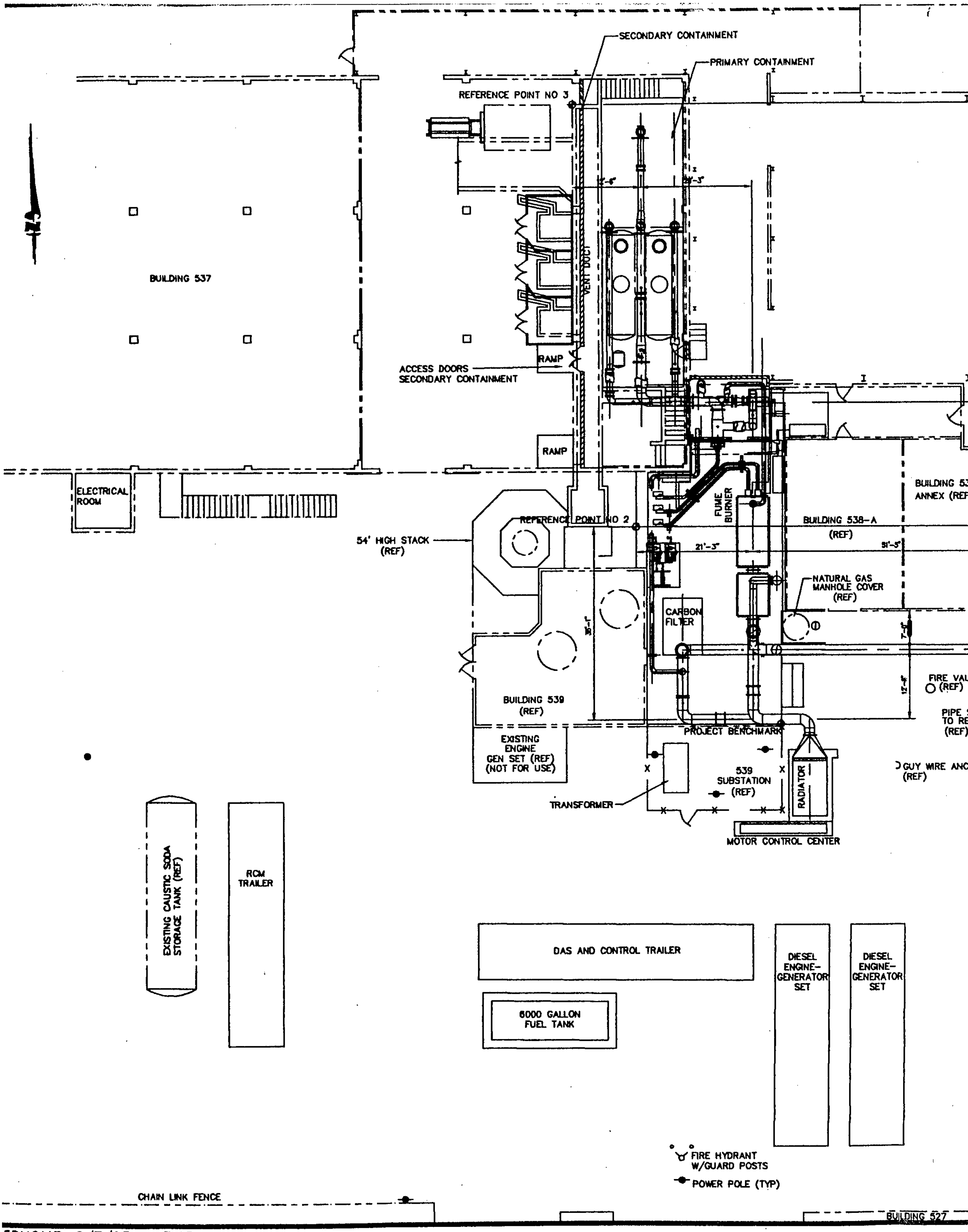
FIGURE 3.1

PROCESS FLOW DIAGRAM

Hot Gas Decontamination System
Rocky Mountain Arsenal
Denver, Colorado

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

2



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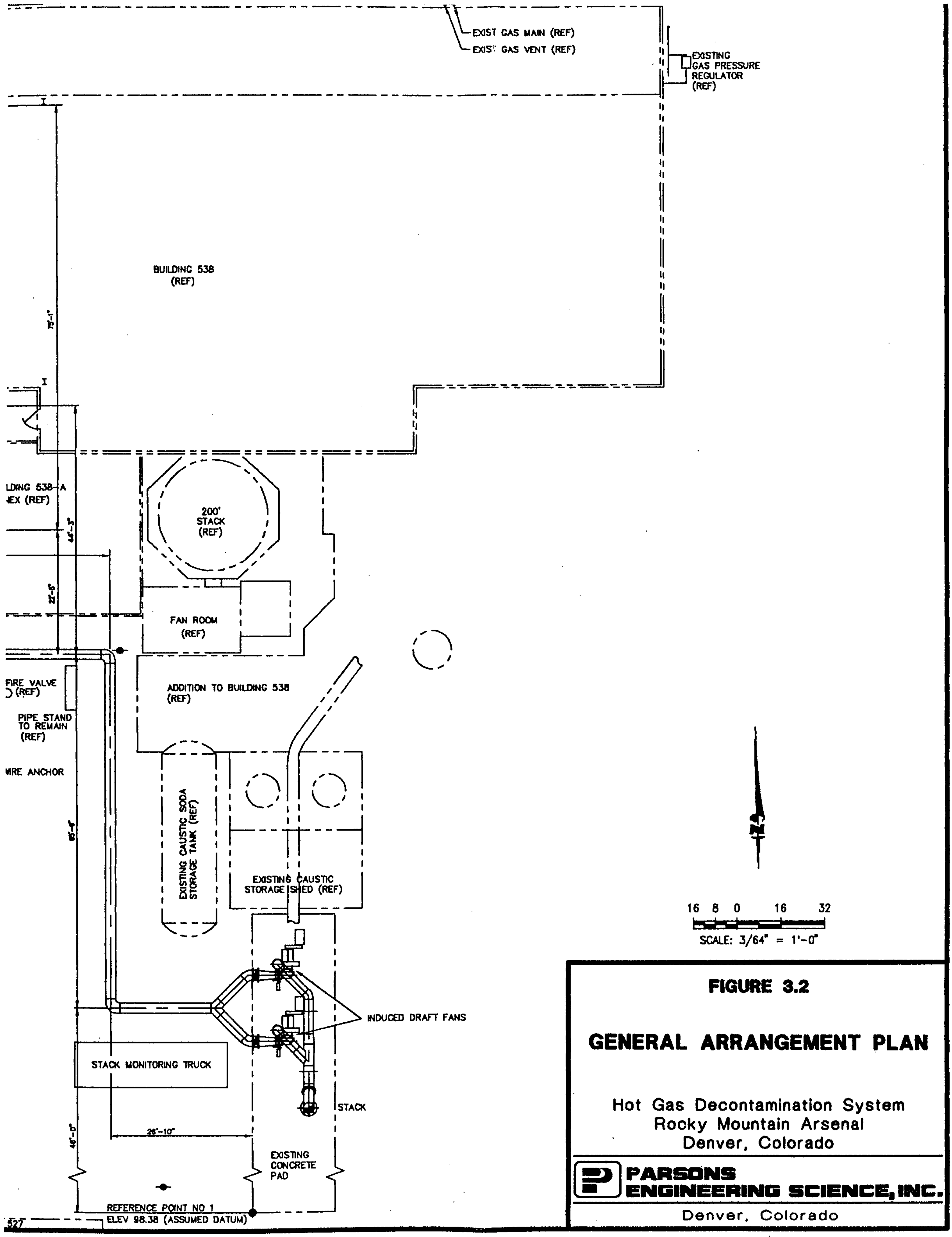

FIGURE 3.2

GENERAL ARRANGEMENT PLAN

Hot Gas Decontamination System
Rocky Mountain Arsenal
Denver, Colorado

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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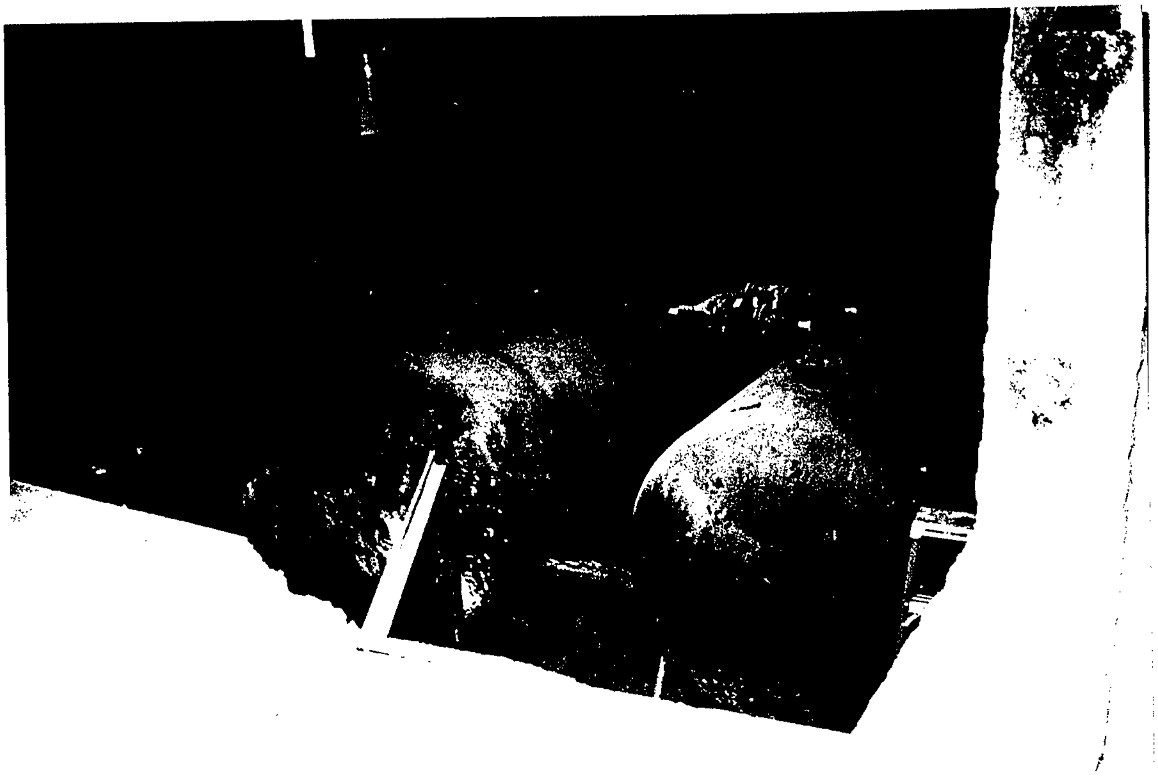
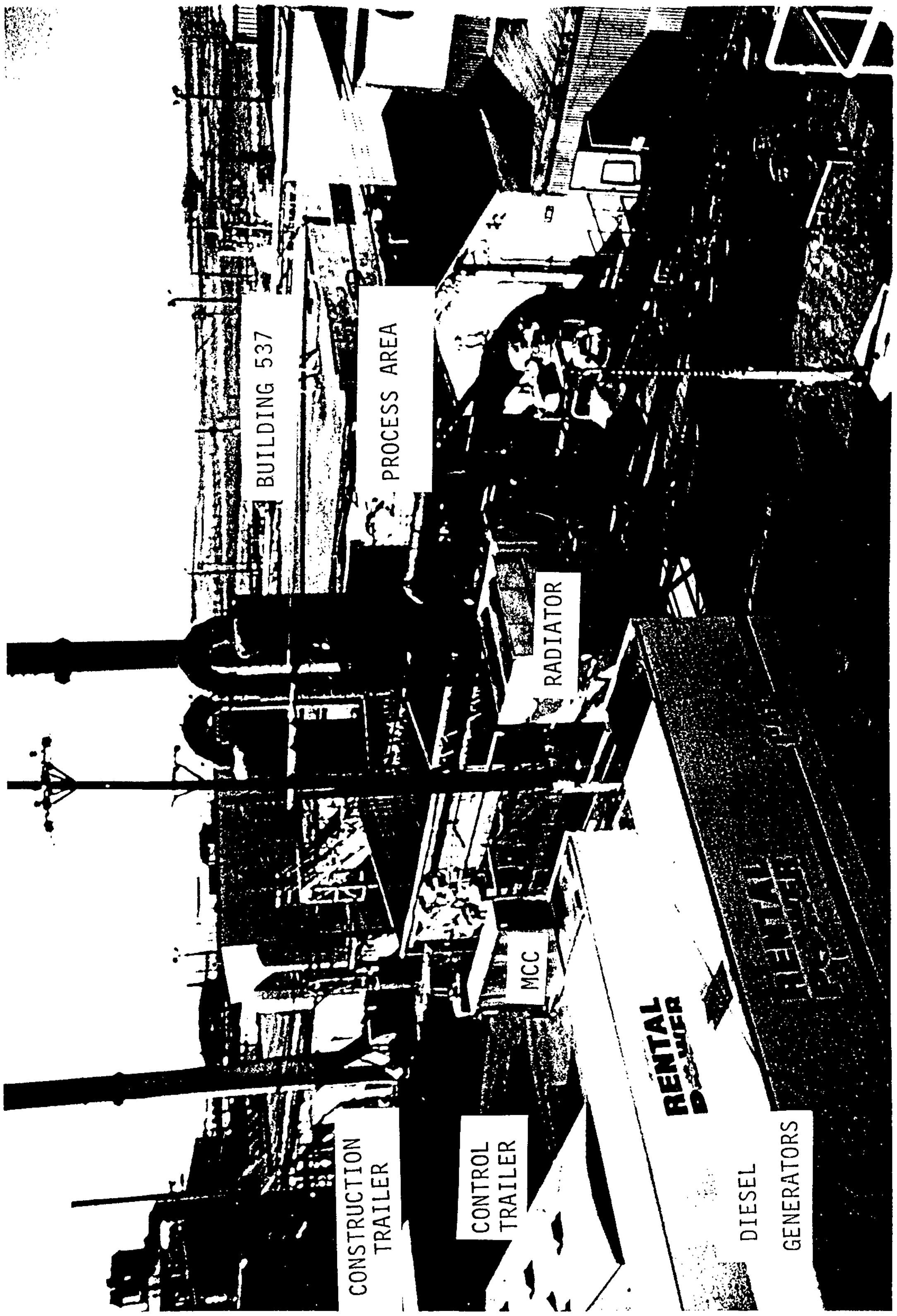


MUSTARD PIT - VIEW FROM SOUTHEAST

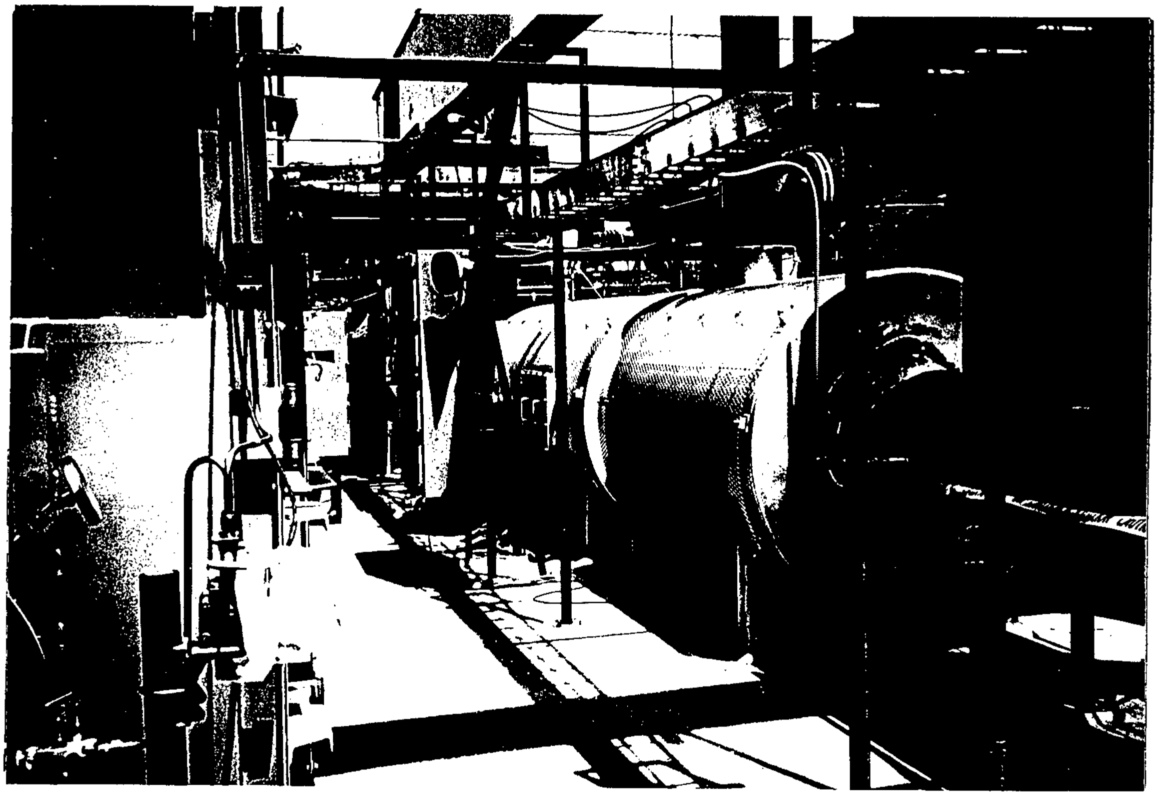
MUSTARD PIT - OVERVIEW FROM SOUTH

FIGURE 3.3a

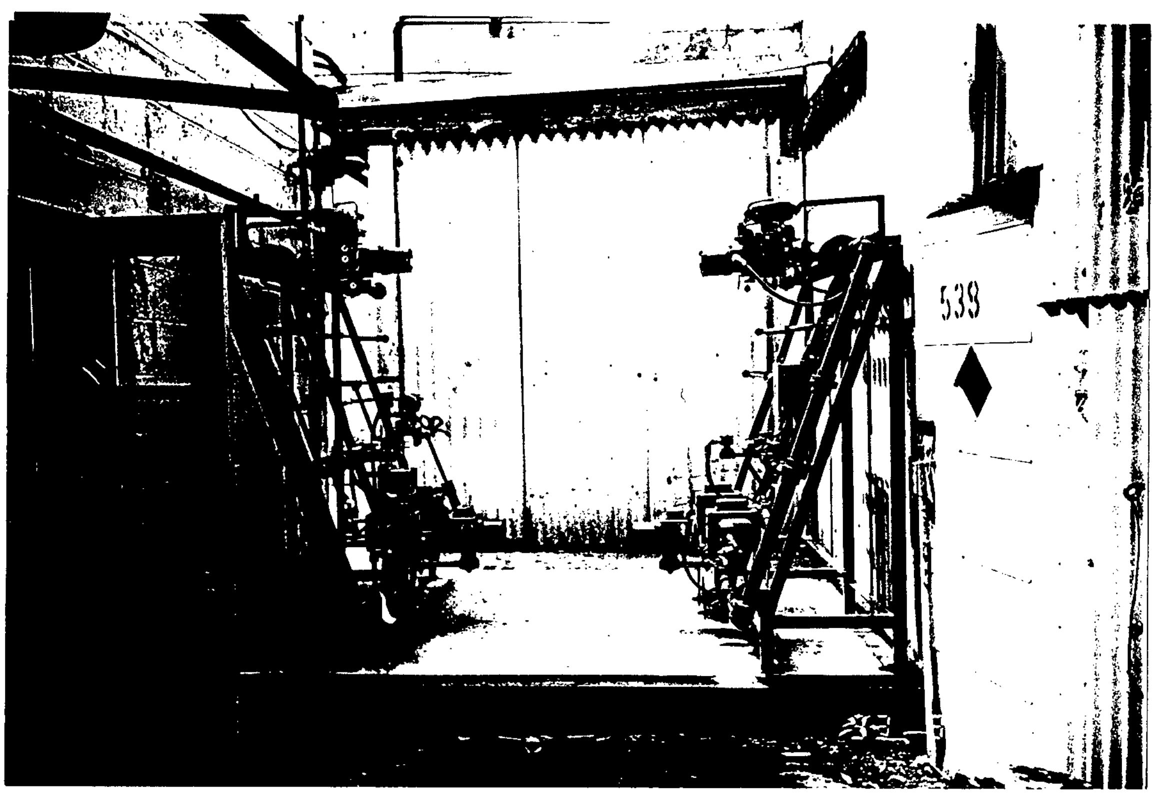


HGDS SITE OVERVIEW

FIGURE 3.3b

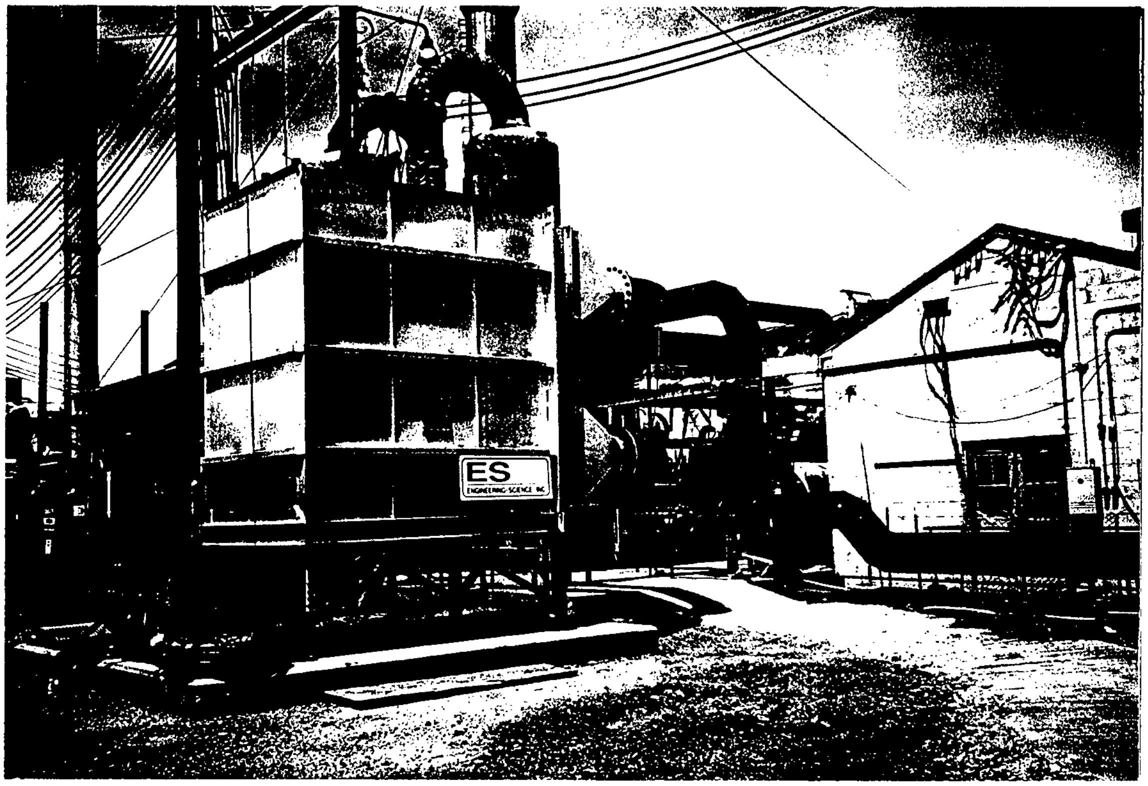


FUME BURNER AND MIXING CHAMBER

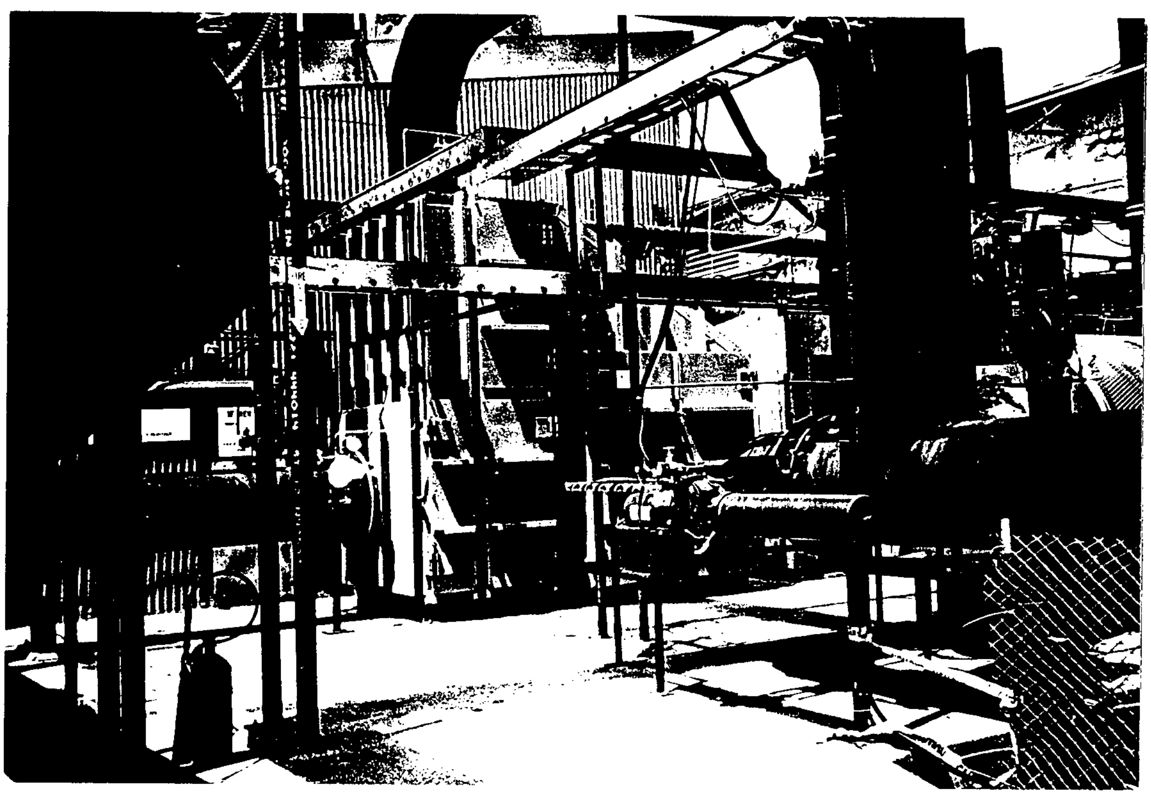


FUME BURNER GAS TRAINS

FIGURE 3.3c



RADIATOR AND PROCESS AREA



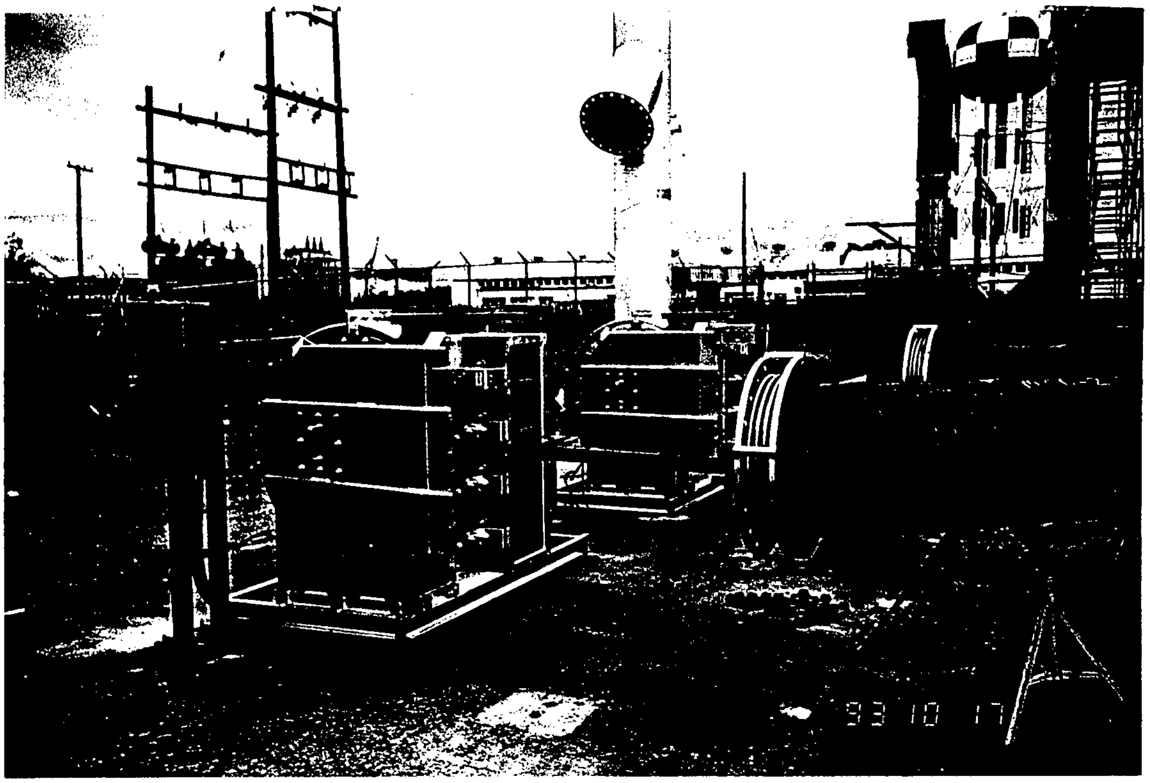
CARBON FILTER AND PROCESS AREA

FIGURE 3.3d

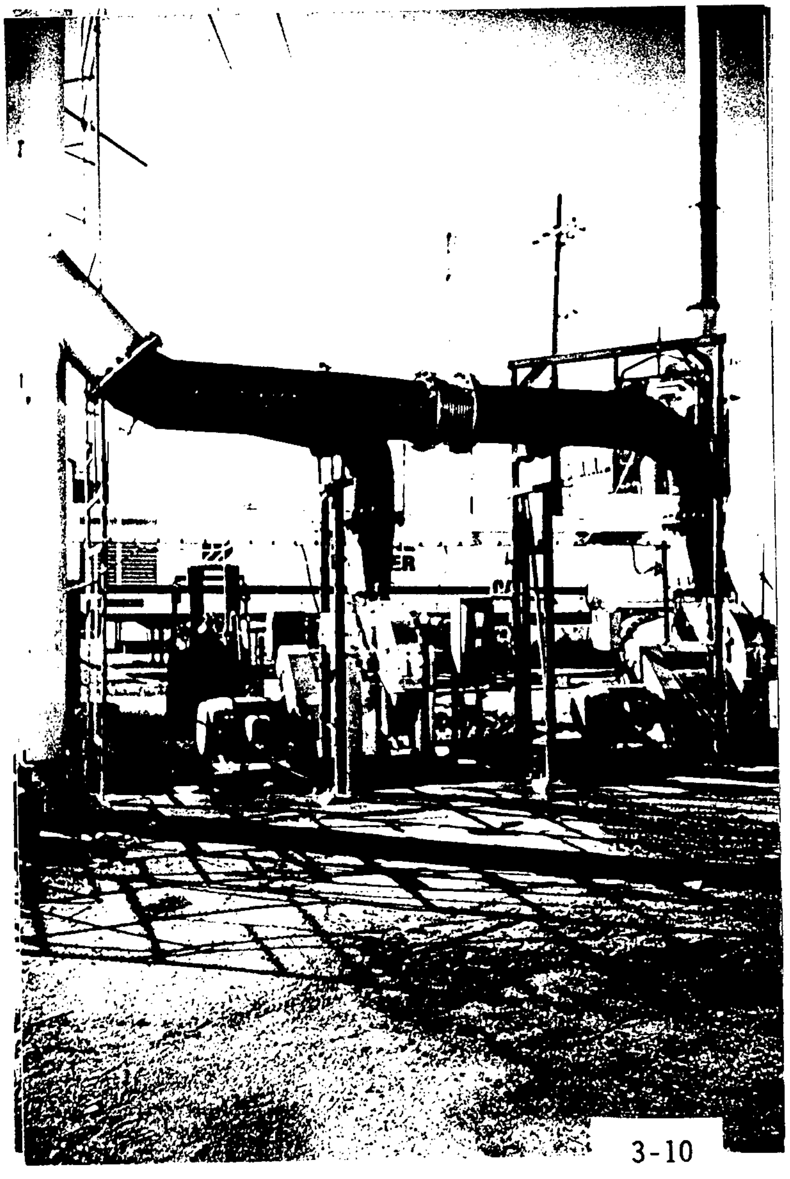
STACK AND MONITORING PLATFORM

STACK ASSEMBLY

FIGURE 3.3e

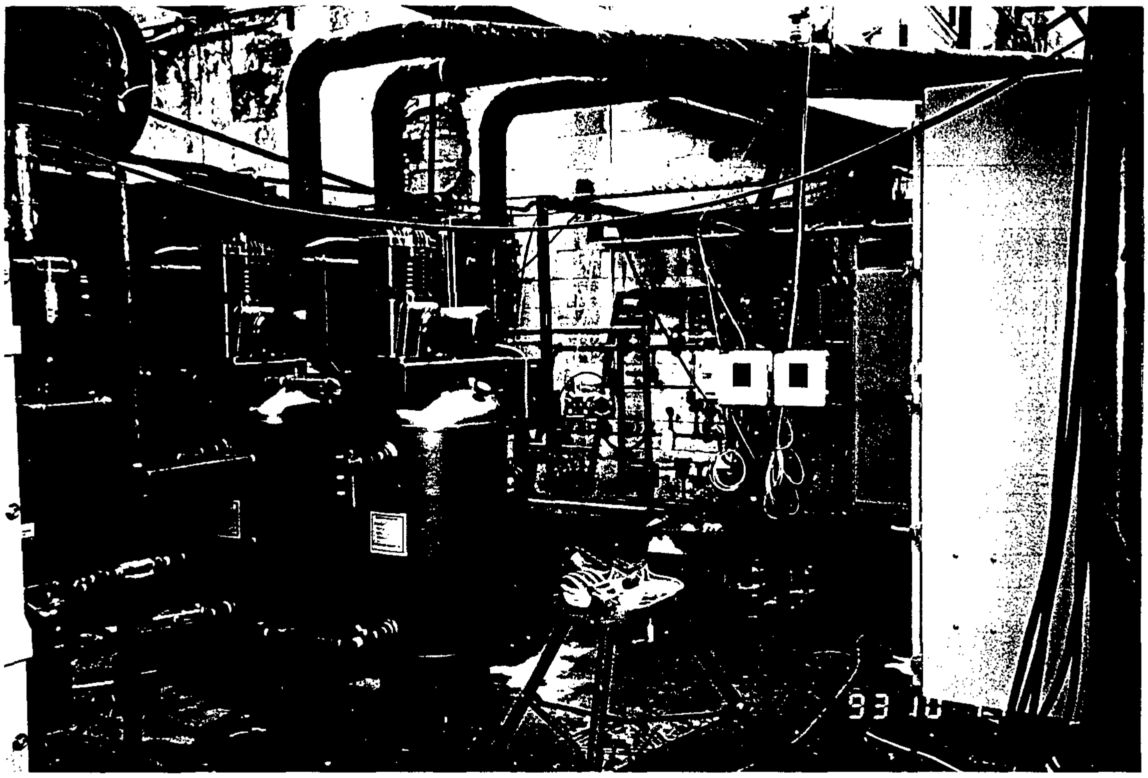


ID FANS WITH DAMPERS DURING INSTALLATION

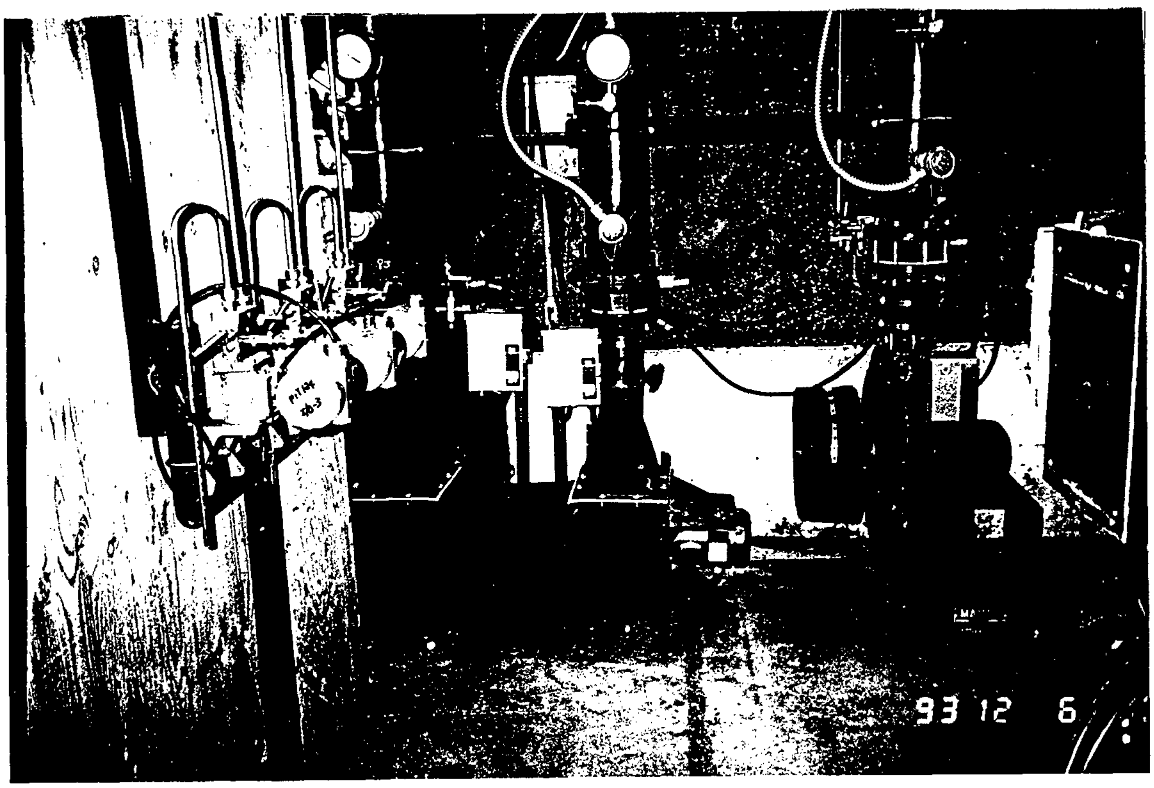


ID FANS AFTER INSTALLATION

FIGURE 3.3f

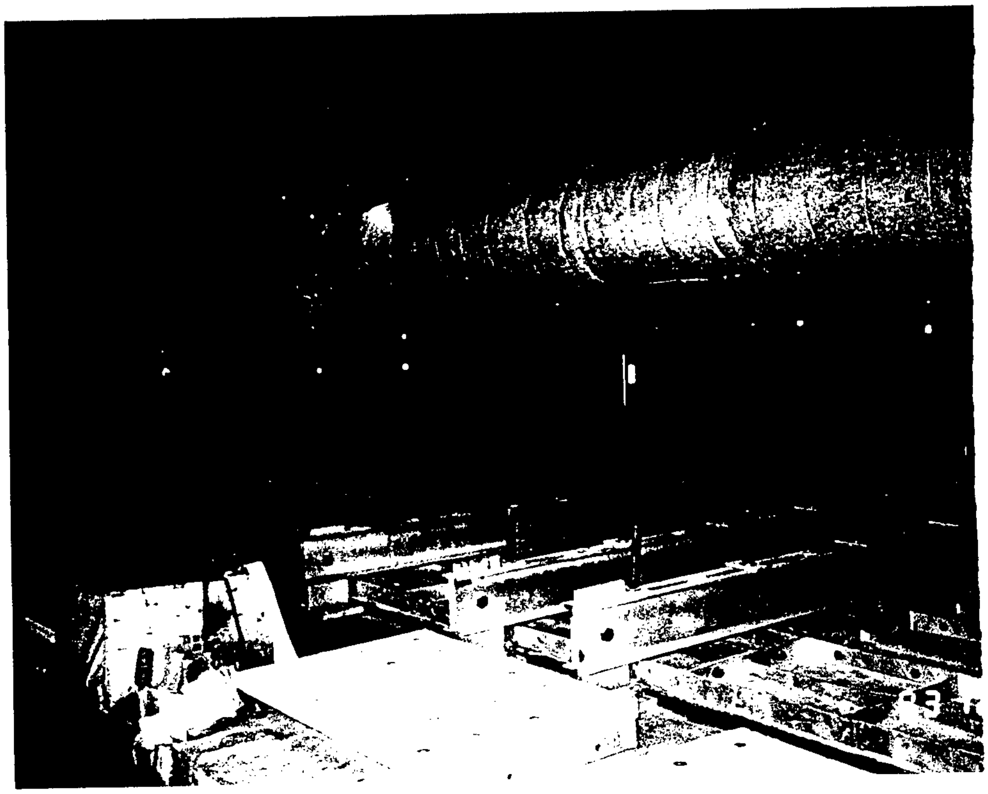


INSTRUMENT AIR COMPRESSORS

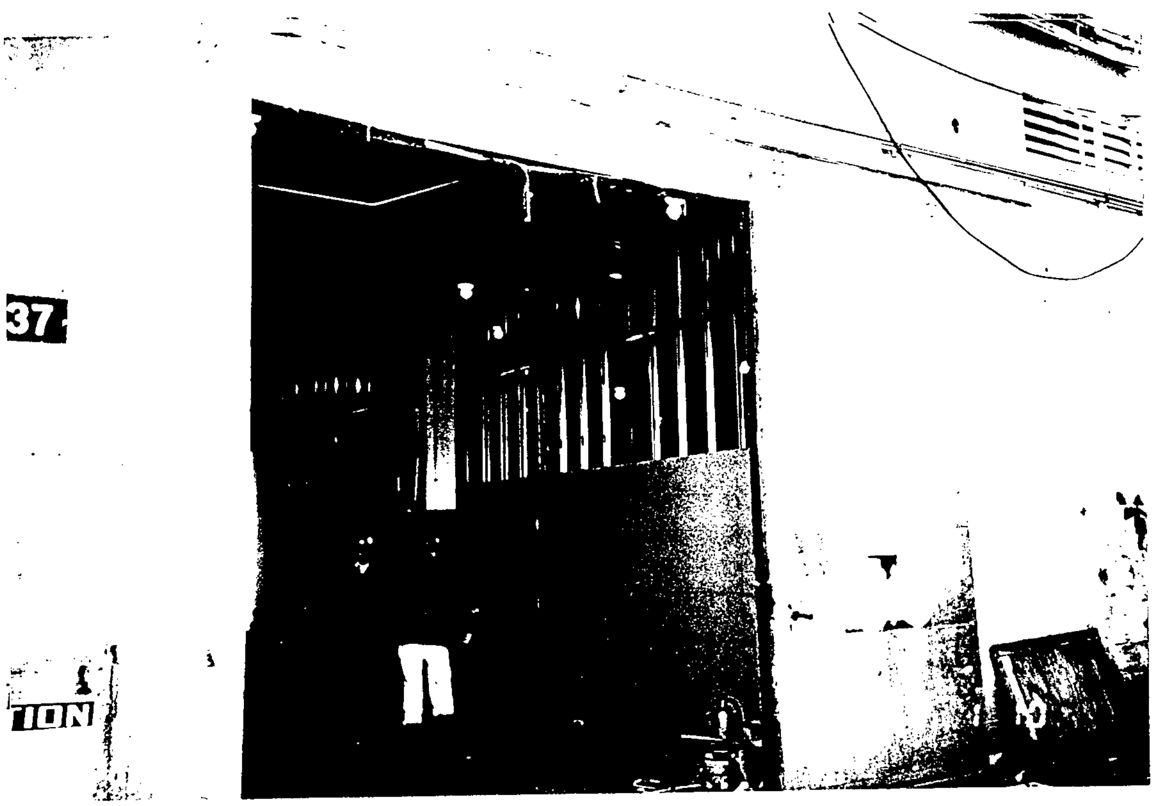


COMBUSTION AIR FANS

FIGURE 3.3g

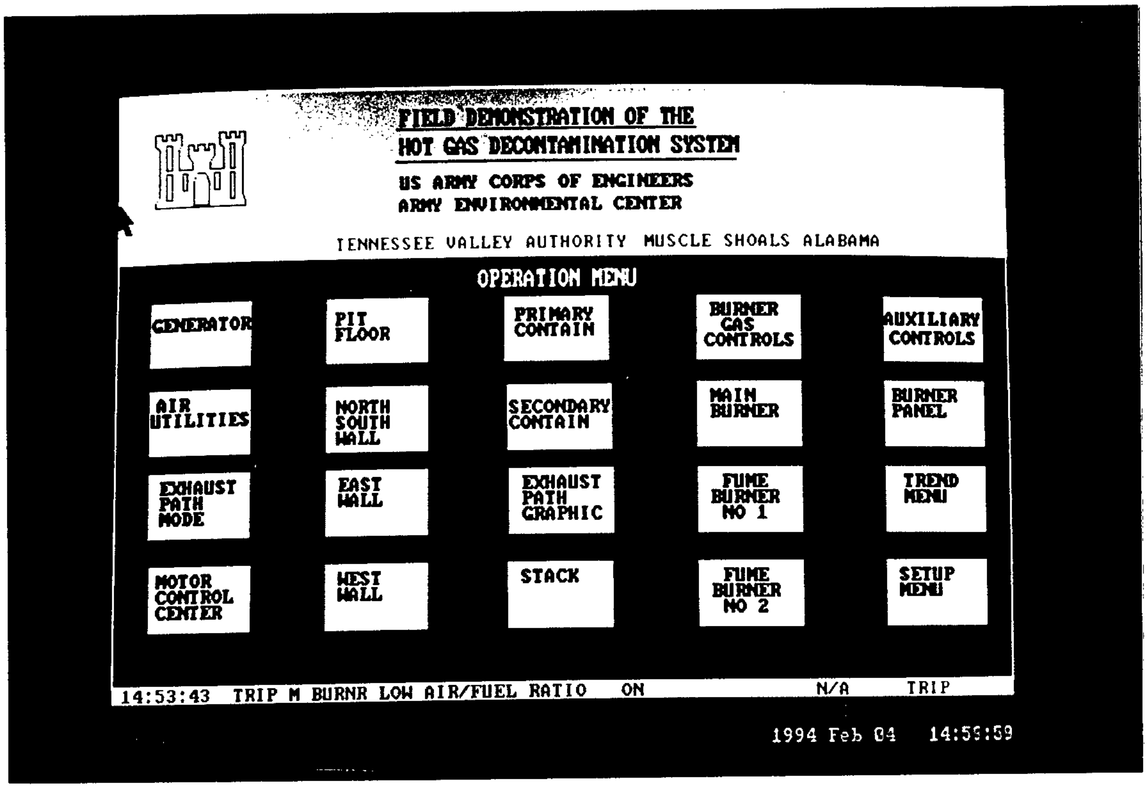


PRIMARY CONTAINMENT AND HOT AIR SUPPLY PIPING

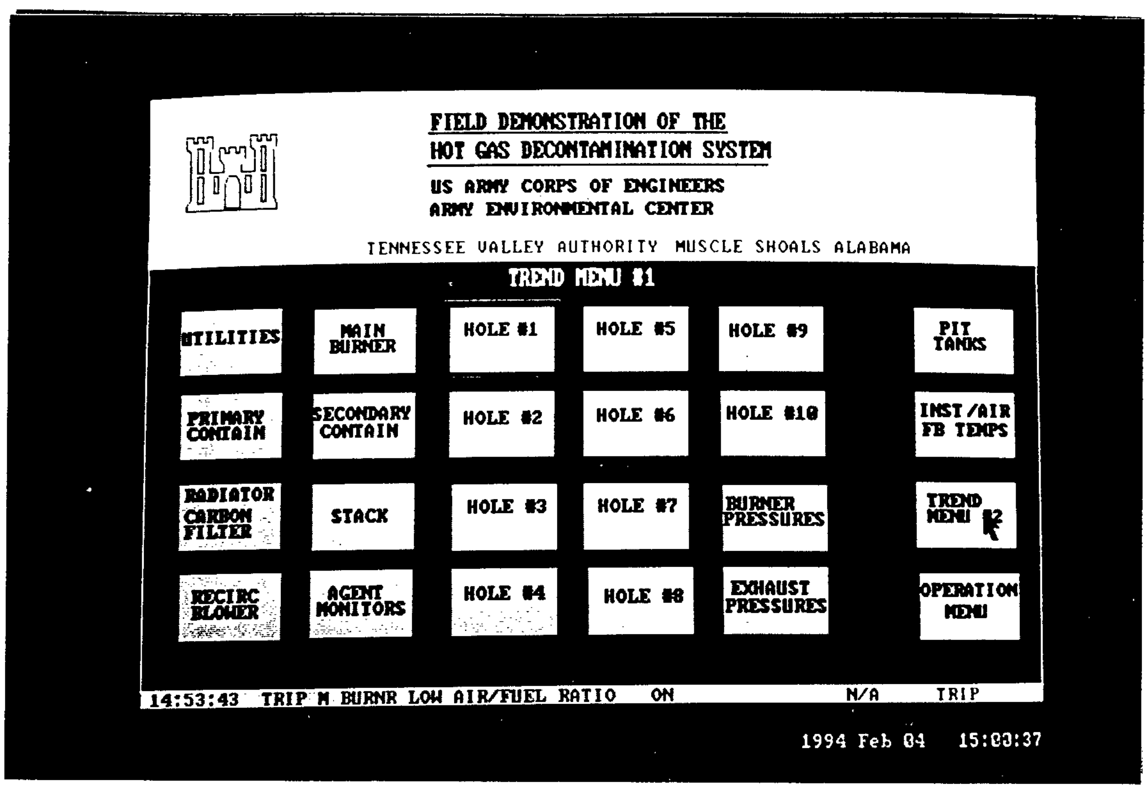


SECONDARY CONTAINMENT, UNDER CONSTRUCTION, BUILDING 537

FIGURE 3.3h

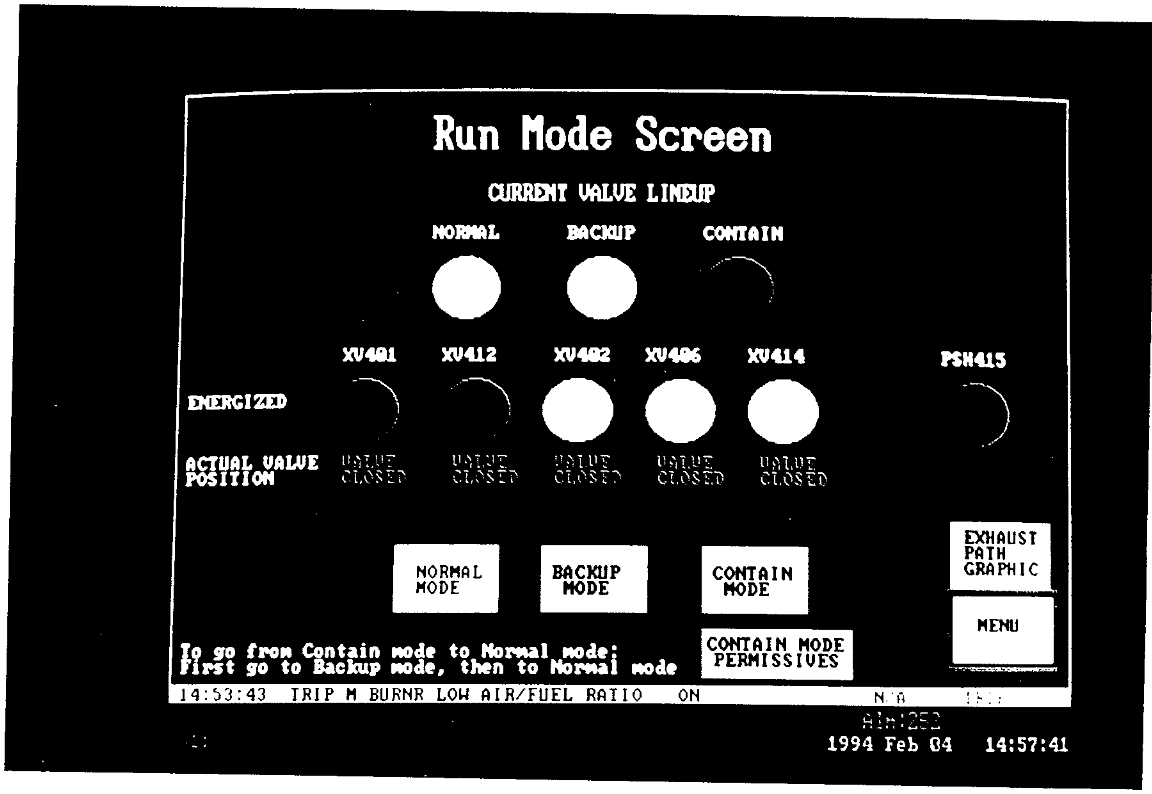


OPERATION MENU AT MAIN CONTROL PANEL (MCP)

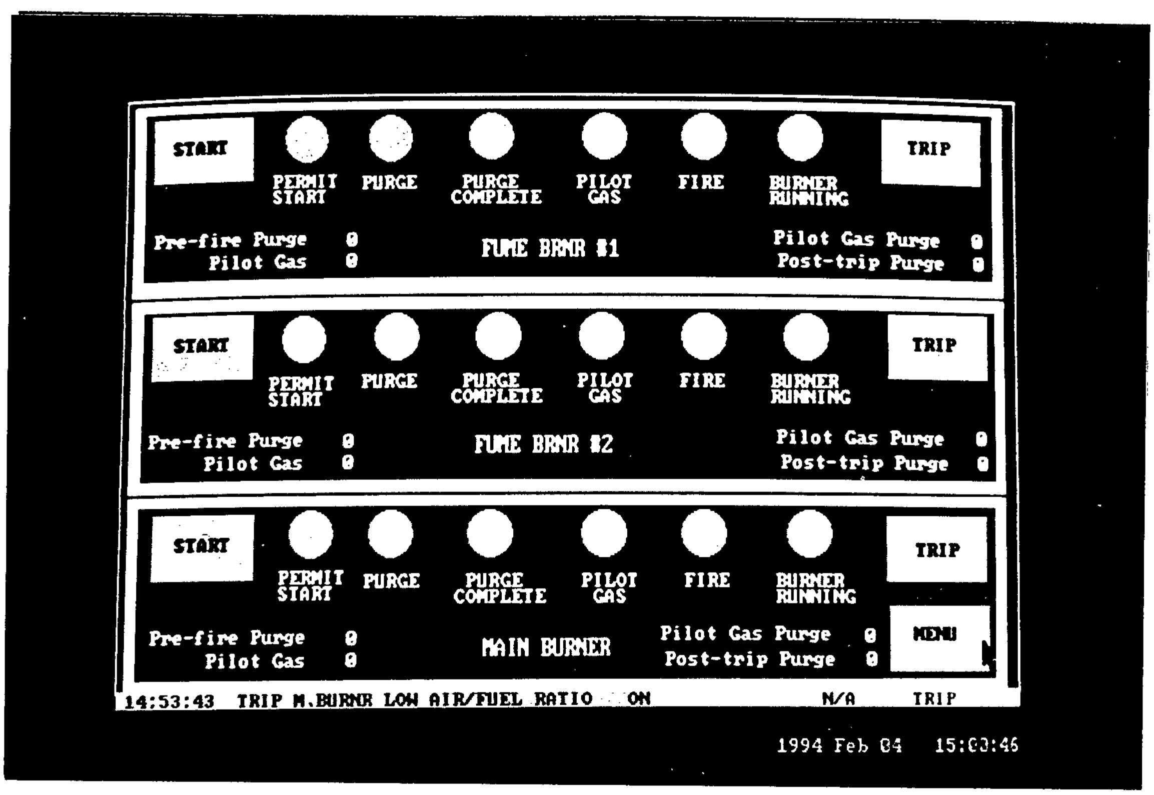


TREND MENU AT MCP

FIGURE 3.3i



RUN MODE SCREEN AT MCP



BURNER START SCREEN AT MCP

FIGURE 3.3j

to the fume burner and could be monitored at the stack. The controls also prevented the main burner from being started until the fume burner was operational and the system was under negative pressure. Once the pit was hot, the fume burner was not shut down until the pit had cooled down. There were conventional burner controls and safety devices on all burners. Power to the control system was backed up with the secondary power supply.

Heatup of the pit began at a low temperature and was ramped up in pre-planned increases based on the temperatures, pressures, and content of the gases leaving the pit. Combustible material was removed from the pit prior to the start of the HGDS demonstration.

Natural gas for firing the burners was supplied from existing gas pipelines from Public Service Co. of Colorado through a gas service connection constructed as part of the HGDS.

A rented air compressor and filtration system furnished instrument air for the automatic valves and system equipment.

No potable water or sewer system was available at the South Plants at RMA. Bottled drinking water was available at the site. Portable toilets were located onsite for sanitary use.

Waste minimization was a primary criterion in development of the system design. Uncontaminated waste (trash) was processed by the RMA trash disposal system. All wastes subject to potential contamination were tested, segregated and disposed of according to appropriate PMRMA protocol.

The field demonstration generated a minimum of wastes, which included:

(1) Used carbon from the carbon filters

(2) Solvents and water used in cleaning of sampling equipment and glassware used in sample collection and analysis operations

(3) Protective clothing worn during sampling and analysis operations

During operations, wastes were contained, labeled, and stored according to waste disposal procedures required by Program Manager Rocky Mountain

Arsenal (PMRMA). Contaminated waste was stored in drums on-site during the field demonstration, and disposed of according to PMRMA protocol. The used carbon and filter trays will be treated as contaminated waste and disposed of according to PMRMA protocol.

3.2 DESIGN CONSIDERATIONS

3.2.1 General Criteria and USAEC-Furnished Direction

The primary design criteria for the Hot Gas Decontamination System are summarized as follows:

- The target contaminated area (mustard pit) and contents should be heated to 350 °F and maintained at that temperature for 24 hours.
- A fume burner treatment system treats exhaust gas at 2,000 °F for a residence time of 2 seconds.

Other fundamental design criteria for the HGDS process equipment, pit modifications, primary containment, secondary containment, and support equipment include the following:

- Promote worker and public health and safety.
- Protect the environment.
- Economize on cost of the project.
- Minimize waste on construction and operation of the system.
- Provide containment structures around potential emissions sources.
- Maintain all equipment and structures in the system under negative pressure, such that potential fugitive emissions or leaks are directed inward and toward the treatment system.
- Conduct operation of the Field Demonstration in winter months, to utilize ambient temperatures to contain fugitive off-gasing from the surrounding area.
- Protect the structure of Building 537 from damage.
- Protect surrounding buildings from damage.

- Use existing structures for shelter to support the project with the permission of Program Manager Rocky Mountain Arsenal (PMRMA). If existing equipment or structures are used, assure that the project results cannot be biased.

- No large structures or highly visible objects, such as tall stacks.

- No digging or intrusive activities.

- Minimize fugitive dust emissions during construction and operation.

- Remove all project facilities after the project is completed.

- No potable or process water is available at the site. Minimize process water usage.

- No industrial or sanitary sewer facilities are available at the site. Minimize wastewater generation.

- No release of water (such as clean cooling water) to the surface at the site.

A primary design and operating criterion for the HGDS called for the system to be constructed and operated in the colder months of the year (late fall, winter, and early spring). This criterion was adopted to utilize ambient air temperature to suppress fugitive emissions from the pit. Mustard tends to become more volatile at 40 to 50 °F, creating a health hazard to site workers.

A Preliminary Hazards Analysis and Failure Modes and Effects Analysis were prepared which analyzed the HGDS for safety risks. Major subsystems were examined in the analyses, and a risk assessment was conducted, including evaluation of hazard severity and probability of occurrence. Several mitigating measures, recommended by the hazard analysis engineers, were incorporated into the process system to address potential safety hazards.

The HGDS was furnished with redundant equipment for critical safety systems. Process redundancy includes a backup carbon filter treatment system for the primary fume burner treatment train. Several unit processes are provided with redundancies, including dual fume burners operating at 50 percent of capacity, and the two ID fans operating at 50 percent of capacity.

A redundant power supply, consisting of three sources of power (two generators and power line), was provided.

A thermal analysis was performed for the heatup and cooldown of the HGDS. The analysis considered the geometry of the pit, thermal conductivity of the concrete and adjacent soil, and thermal processes at work. The analysis used predetermined temperature limits for the concrete structure to maintain its structural integrity. This includes a maximum temperature of the concrete of 750 °F, and a maximum temperature gradient across the concrete of 200 °F per foot of concrete. A one-dimensional, transient heat conduction model, with a composite semi-infinite medium and prescribed heat flux, was used to solve the heat transfer problem. This model conservatively simulated the heat transfer in the pit. The model was used to determine the heat requirements for the main burner, and the heatup time for the mustard pit to reach temperature criterion. An estimated heatup time of 11.5 days was calculated for pit heatup to design temperature. Similarly, the cooldown of the pit was evaluated, and a cooldown time of 14 days was calculated.

3.2.2 Process Equipment Design Considerations

The principal components of the HGDS, their design operating capacities, temperatures, and pressures are listed in Table 3.1. The process system and primary components are described as follows.

3.2.2.1 Main Burner

The main burner produced heat which was directed into the Mustard Thaw Pit through a ductwork system. The main burner was natural gas-fired, and included a combustion air blower, fuel and air control valves, and a gas train. The pit heatup was based on a calculated heatup rate which was dependent on the structural limitations of the concrete in the pit. The main burner could be adjusted to control heatup rate. During cooldown, the main burner was shut down while the remainder of the system was maintained on-line.

Thermocouples were placed in the mustard pit to monitor the temperature of the pit. After the last thermocouple reached the required temperature criterion (350 °F), the pit was maintained at that temperature for 24 hours. The two-week cooldown period was initiated immediately after the heat soak.

TABLE 3.1. HOT GAS DECONTAMINATION SYSTEM PRINCIPAL COMPONENTS AND THEIR FUNCTIONS

COMPONENT	FUNCTION	SIZE	PERFORMANCE RATING
Main Burner	Generates hot gases that volatilize agent.	1,000,000 BTU/HR input of 831 BTU/FT^3 natural gas	750 °F minimum with 10-1 turndown ratio
Recirculation Blower	Recirculates heated air from the pit in order to improve heat transfer and mixing, and minimize the exhausted volume of hot gas.	25 HP	5800 ACFM @12 in W.G., 550 °F gas temp.
Fume Burner	Destroys volatilized agent and organics in exhaust gases from pit.	2,500,000 BTU/HR input of 831 BTU/FT^3 natural gas	2,000 °F minimum with 6-1 turndown ratio
Mixing Chamber	Provides mixing of secondary containment ventilation air and ambient air with fume burner exhaust to provide cooling.	66 ½" Dia x 108" long	2,000 °F gas inlet, 575 °F gas outlet
Radiator	Cools fume burner exhaust prior to entry to carbon filter under backup mode conditions.	120" x 90" x 139" high	575 °F gas inlet 120 °F gas outlet
Carbon Filter	Treats secondary containment ventilation air and backup air treatment in the event of fume burner flame out; captures volatilized organics in exhaust gas.	124" long 76" wide 120" tall	1500 ACFM @ 120 °F normal flow 4,500 ACFM @ 120 °F emergency flow.

COMPONENT	FUNCTION	SIZE	PERFORMANCE RATING
Induced Draft (ID) Fans	Maintain negative pressure inside equipment and structure; control agent release to atmosphere.	100 HP	8100 ACFM @ 30" W.C. 575 °F gas temperature.
Stack	All components disperse treated exhaust gases.	24" OD x 55′ high	8100 ACFM @ 575 °F
Control System	Provides feedback to operators to achieve the desired results based on input provided by instrumentation (e.g., thermocouples, pitot tubes, or agent sensors) located throughout the decontamination system. Many of the instruments are included for safety measurements; some are included to optimize system performance, and others record data required for test validation.		

The design criteria provided by USAEC required that the main burner be sufficiently sized to heat the entire cross-section of the concrete walls and floor of the mustard pit to 350 °F, and maintain this temperature for 24 hours. The design duty of the main burner was 750,000 Btu/hr, rated at a natural gas heating value of 831 Btu/std.cu.ft. The temperature rating of the main burner was 750 °F minimum. The design criteria data sheet for the main burner is presented in Table 3.2.

The main burner as procured was sized greater than the design duty and was rated at 1,000,000 Btu/hr. The burner unit was a Maxon Corporation Series 2 G Kinemax medium velocity burner, furnished by the Coen Company, Inc. The main burner was started up under the direction of a Coen representative. The burner was natural gas-fired, and was purchased with a combustion air blower and gas train. The main burner flame was directed into a 2-foot diameter by 6-foot long stainless steel shroud assembly, custom fabricated with a gas

Table 3.2

BURNER DESIGN CRITERIA

Location: Denver, Colorado (Adams County)

Temperature: Outdoor winter minimum -10° F Outdoor winter maximum 70° F

Elevation: 5,300 above sea level
Installation: Indoor ________, exposed to weather ___x___
Environment: Relatively clean ___x___, dusty _______, corrosive _______
Service: ___24___ hrs. per day, ___7___ days per week
Available utilities:
Electric supply: ___480___ volt, ___3___ phase ___60___ hertz
Electric supply: ___120___ volt, ___1___ phase ___60___ hertz

DATA SHEET

REQUIREMENTS DESCRIBED	SPECIFIED VALUE
1. Main Burner	
Fuel	Natural gas, 831 BTU/FT^3
Burner rating	1,000,000 BTU/hr minimum
Burner Operating pressure (in. WG)	$-\frac{1}{2}$
Temperature rating (°F)	1500 minimum
Turndown ratio	10 to 1
Combustion air blower	no, separate
Gas train	yes
2. Fume Burner	
Fuel	Natural gas, 831 BTU/Ft^3
Burner rating (each)	2,500,000 BTU/Hr minimum
Burner operating pressure (in. WG)	-2
Temperature rating (°F)	2,000 minimum
Turndown ratio	6 to 1
Combustion air blowers (2)	no, separate
Fume burner, residence time, seconds,	2
Gas train	yes
Shell design pressure (in. Hg)	10

reheat section. The main burner housing was field-assembled at the site. There was no redundant equipment furnished in the main burner system, except a shelf spare burner assembly and combustion air blower. This was due to the fact that the main burner was not part of any safety system, and time could be allowed for repair of the main burner in the event of failure.

Main Burner System Controls

An operating light and alarm at the Main Control Panel (MCP) indicated on/off operating status of the main burner. The temperature at the combustion air blower discharge was monitored locally and displayed on the MCP. Pressure at the blower discharge was transmitted for display on the MCP. A flow control loop consisting of a mass flow transmitter, flow controller, and control valve maintained the air flow at the proper rate. A backup control configuration allowed the flow controller to readjust the setting of the control valve to allow draft from the induced draft fans through the blower assembly to preclude shutdown of the main burner in the event of blower failure. Flow alarms were activated should the air flow to the burner go beyond the preset limits. Position indicators on the control valve indicated "Lightoff" position or "Purge" position.

Fuel gas was supplied by Public Service Company of Colorado through the RMA natural gas pipeline at 20 psig, which was reduced to 2 psig by a pressure regulator. A local pressure gauge and transmitter communicated the pressure to the MCP. Alarms and automatic shutoff valves with fail closed or fail open features were provided for safety. A flow control loop consisted of a mass flow transmitter and flow controller with control valve and maintained the preset firing rate of the main burner. A separate valve and safety system was provided for the pilot gas, which was reduced to 1.5 psig by a pressure regulator, and monitored at the MCP. Similar alarms and automatic shutoff were provided for the pilot gas.

Main burner operation could be terminated by low fuel gas pressure, high fuel gas pressure, high burner temperature, and burner flame out. To start or restart the main burner, a system purge procedure must be followed for safe operation, requiring manual reset of the gas control valves.

A temperature controller controlled the firing rate of the main burner and received its set point from a temperature indicator. The system permitted two controlled rates of firing, either from the main burner outlet or from the mustard pit. Trending and high alarms of both signals at the MCP were provided, as well as a high temperature shutdown. A local temperature indicator was provided at the burner.

Pit Heat and Distribution Controls

Concrete temperatures in the mustard pit were monitored during heatup and cooldown by 117 thermocouples installed in the pit floor and walls. The thermocouples are described in detail in Section 3.2.3. This temperature data was displayed and trended at the control computer. Also, the 117 points were grouped and averaged to indicate hot and cold spots. The control program contained data variation limits that triggered alarms to pinpoint the hot and cold spots. Heat was input and distributed to the pit with the objective of uniform heating over the floor and walls. Plant operators corrected uneven heating by reducing or increasing the main burner output, or by modulating the inlet distribution valves.

The three control valves on the pit inlet ductwork directed and distributed the main burner heat input to the north, center, and south areas of the pit. Throttling these valves controlled the distribution of the heat to the respective areas to provide uniform heating throughout the pit. Control of the valve setting occurred at the MCP, where a valve position indicator was displayed.

Pressure in the mustard pit was displayed and trended on the MCP, and provided with high and low pressure alarms.

3.2.2.3 Fume Burner

The fume burner unit was designed to provide 2 seconds of residence time at 2,000 °F, and destroyed toxic components in the pit exhaust gas. Two burners in this unit were equally sized at 100 percent capacity to provide duplicate flame sources to reduce the risk of failure. As the primary exhaust treatment system, a fully redundant burner was required for safety purposes.

The burners were natural gas-fired and each included a combustion air blower, fuel and air control valves, and a fuel safety train. The two burners were operated simultaneously at 50 percent load during normal operation. If one burner failed, the other burner ramped up to provide full (100 percent) load. The burner that failed can then be checked, repaired, and returned to service without a complete shutdown.

The design criteria data sheet for the fume burner is presented in Table 3.2. The design duty of the fume burner was 2,000,000 Btu/hr, rated at a natural gas heating value of 831 Btu/std.cu.ft. The burners as purchased were rated at 2,500,000 Btu/hr. The temperature rating of the fume burner was 2,000 °F minimum. The fume burner assembly was manufactured by the Coen Company, Inc. The fume burners were started up under the direction of a Coen representative.

The fume burner chamber provided the residence time for exposure of the exhaust gas to the burner heat. Each burner flame was directed into the head end of the fume burner chamber. The chamber was a cylindrical steel vessel, 6-foot diameter and 12 feet long, and lined with refractory brick. A steel safety guard was placed on the outside of the chamber for worker protection. Each burner in the fume burner was provided with a view port to visually observe the burner flame.

Fume Burner Control

The temperature and pressure at each combustion air blower discharge were monitored and displayed on the MCP. Flow control loops consisting of individual mass flow transmitters, flow controllers, and control valves maintained a constant air flow to the burners. Flow alarms activated when the air flow varied from preset limits.

For fuel gas, a local pressure gauge after the pressure regulator on the natural gas supply was provided, and gas pressure data was transmitted to the MCP. High and low pressure alarms were provided, and burner shutdown was initiated if the gas pressure dropped too low or in the event of an electrical power failure. Flow control loops consisting of individual mass flow elements, transmitters, valve positioners, and control valves maintained the preset burner firing rate. The control valves were equipped with position indicators showing "Lightoff" or "Purge" position.

For pilot gas, a similar control system included a local pressure gauge and transmitter to the MCP. Alarms were activated for low and high pressure, and the high pressure alarm would interrupt the start sequence during burner startup. In case of power failure or automatic shutdown, gas safety valves would close the pilot gas supply.

The fume burners would be shut down by low or high fuel gas pressure, electrical power failure, or burner flameout. Flameout was sensed by ultraviolet flame sensors for each burner. If both ultraviolet flame sensors failed to detect a flame, an alarm is activated, followed by closure of the automatic gas safety valve. To start or restart burners, the gas safety valves must be manually reset with a manual reset lever. The burner system start control was located at the MCP. A pre-programmed sequence for safe burner starts included timed intervals for purge cycles, valve open and close cycles, and igniter energization.

3.2.2.4 Mixing Chamber

A mixing chamber was located immediately downstream of the fume burner to facilitate cooling of the fume burner exhaust gas. The purpose of the mixing chamber was to cool the process gas so that standard materials of construction (carbon steel) can be utilized for downstream equipment. The mixing chamber provided cooling of the fume burner exhaust by injection and mixing of ambient cooling air. Two sources of cooling air were utilized to reduce the gas temperature below 575 °F, which is below the practical limit for carbon steel. Ventilation air from secondary containment (which had been previously treated in the carbon filter) and outside ambient air were mixed with the hot process gas to cool the exhaust temperature below 575 °F.

Also, the mixing chamber reduced the temperature of the fume burner exhaust to contribute to cooling in the backup carbon filter/radiator train. The mixing chamber was of similar design and construction to the fume burner chamber, and was purchased from the Coen Company as a package with the fume burner.

The mixing chamber was a design feature of the system which eliminated the requirement for a quench system and cooling water. This, in turn, reduced the overall project cost and waste generation.

Mixing Chamber Control

A temperature control loop consisting of a temperature transmitter, valve positioner, and control valve admitted ambient air to the mixing chamber according to an automatic operator-adjustable program.

An agent analyzer located between the fume burner and mixing chamber monitored agent concentration of the fume burner exhaust. This value was displayed at the MCP, recorded, and trended. An alarm was activated if the agent concentration exceeds 0.1 units TWA (0.0003 mg/m^3).

3.2.2.5 Radiator

A radiator system was located ahead of the carbon filter on the backup circuit, and provided temperature protection for the carbon filter. In the backup configuration, the radiator cooled the mixing chamber exhaust to reduce the temperature of the exhaust gas to 120 °F, which is within the efficient operating range for the carbon filters. In the event of fume burner failure, the main burner would be shut down to lower the temperature of the gases leaving the pit. The radiator was a natural draft-type heat exchanger, whose sole purpose was to protect the carbon filter from temperatures above 130 °F in the process gas. The radiator was designed to reduce the temperature of exhaust gas from 575 °F maximum to 120 °F maximum, at a flow rate of 7,700 actual cubic feet per minute (ACFM). The design criteria data sheet for the radiator is presented in Table 3.3.

The radiator was constructed by Des Champs Laboratories Incorporated. During a full-scale test conducted at the manufacturer's plant, the radiator successfully reduced the gas temperature by 487 °F, at a flow rate of 8,100 ACFM and a pressure differential of 1.24 inches. The radiator was mounted on a pedestal to allow for natural up-draft cooling, and has dimensions that were approximately 10 feet long by 10 feet wide by 11.5 feet high.

Table 3.3

RADIATOR DESIGN CRITERIA

Location: Denver, Colorado (Adams County)

Temperature: Outdoor winter minimum -10° F Outdoor winter maximum 70° F

Elevation: 5,300 above sea level
Installation: Indoor ________, exposed to weather ___x___
Environment: Relatively clean ___x___, dusty ________, corrosive ________
Service: ___24___ hrs. per day, ___7___ days per week
Available utilities:
Electric supply: ___480___ volt, ___3___ phase ___60___ hertz
Electric supply: ___120___ volt, ___1___ phase ___60___ hertz

DATA SHEET

REQUIREMENTS DESCRIBED	SPECIFIED VALUE
Rated radiator gas volume capacity at 6 in. WG (ACFM)	7,700
Static pressure at radiator inlet (in. WG)	3.5 negative
Outlet pressure differential (in. WG)	6 negative
Radiator design pressure PSIG	15
Temperature range of process gas entering radiator (°F)	
Maximum	575
Minimum	550
Process temperature leaving radiator	
Maximum	120°
Minimum	100°
Wind velocity (MPH)	0

Similar to the mixing chamber, the radiator provided dry cooling without cooling water with attendant cost savings and waste reduction.

Radiator Control

The radiator/carbon filter backup mode was automatically enabled immediately upon the failure of both fume burners. After a 10-second time delay, the supply of secondary containment air to the mixing chamber was terminated and increased ambient air for cooling was introduced to the mixing chamber. A control valve opened to allow the carbon filter exhaust to flow directly to the induced draft fans.

To achieve a "bumpless" change from the Normal Mode to the Backup Mode, the instantaneous opening of the backup inlet control valve was coupled with a delayed closing of the normal control valves, allowing the alternate path to be opened prior to closing the normal path. Position lights indicated the position of valves at the MCP.

A pressure gauge monitored the inlet pressure, while a thermometer and temperature transmitter monitored the inlet temperature. This data was displayed on the MCP, and the program included alarms and trends.

3.2.2.6 Carbon Filter Unit

The carbon filter served a dual function as a safety backup to the fume burner in the event of fume burner failure, and provided full-time treatment of the ventilation exhaust from the secondary containment during normal system operation. The carbon filter was capable of adsorbing organic vapors from the exhaust gases. The carbon filter contained two banks of filters, each sized for 100 percent capacity.

The carbon filter unit contained multiple filter modules which included a medium efficiency pre-filter, a high-efficiency particulate air (HEPA) filter bank, two activated carbon filter banks in series, and a final HEPA filter bank. The two tray-type activated carbon filter banks conformed to MIL-HDBK-144 Type II. The maximum allowable leakage rate was 0.1 SCFM at 10 inches of water gauge, in accordance with ANSI N509, ESF leakage Class II specifications.

The carbon unit was manufactured by Ionex Research Corporation. The design flow rate was 4,500 ACFM at a negative pressure of 10 inches of water gauge. The capacity of the granulated carbon media was estimated to be 10 times that expected to be processed during the operation of the HGDS. The excess capacity was built into the system to accommodate emergency back-up in the event of fume burner failure or shutdown. The carbon filter unit dimensions were approximately 11 feet long by 7 feet wide by 11 feet high. The design criteria data sheet for the carbon filter was presented in Table 3.4.

Table 3.4

CARBON FILTER DESIGN CRITERIA

Location: Denver, Colorado (Adams County)

Temperature: Outdoor winter minimum -10° F Outdoor winter maximum 70° F

Elevation: 5,300 above sea level
Installation: Indoor ________, exposed to weather x
Environment: Relatively clean x, dusty ________, corrosive ________
Service: 24 hrs. per day, 7 days per week
Available utilities:
Electric supply: 480 volt, 3 phase 60 hertz
Electric supply: 120 volt, 1 phase 60 hertz

DATA SHEET

REQUIREMENTS DESCRIBED	SPECIFIED VALUE
Rated filter capacity at 24 in. WG (ACFM)	4,500
Static pressure at filter inlet (in. WG)	3.5 negative
Dirty Filter final pressure differential (in. WG)	2
Housing design pressure positive or negative (in. WG)	10 negative
Maximum housing leakage rate at 10 in. WG (SCFM/ft^2)	0.1
Temperature range of air entering filter (°F)	
Maximum	120
Minimum	100
Minimum adsorber residence time per bank (sec)	0.25
Access Doors	
Type	Bulkhead
Hinges	Double pin
Self-locking open (w/manual release)	Required
Sample port location, 1" NPT cplg.	Between charcoal adsorber banks (MINICAMS)

Redundancy in treating the secondary containment ventilation air at the carbon unit was addressed by excess carbon capacity in the unit. The monitoring point in the carbon unit was placed at the midway point of the unit, so that orderly shutdown of the system could occur in the event of breakthrough at the midpoint.

Carbon Filter Control

A local pressure gauge monitored inlet pressure, while inlet temperature and differential pressure across the filter bank were communicated to the MCP. The alarms were activated for high differential pressure and high temperature.

An agent analyzer (Minicam) monitored the agent level between the two banks of filters in the carbon filter, and agent concentration was communicated to the MCP with an alarm set for 0.1 units TWA.

3.2.2.7 Recirculation System

A recirculation system was utilized, which reduced the size, cost, and energy consumption of the HGDS. A recirculation fan recirculated much of the heated pit exhaust back to the pit. The recirculation system was designed to recirculate exhaust gas exiting the mustard pit back to the inlet manifold, where it was blended with fresh heated air from the main burner and injected into the pit. The recirculation fan delivered process gas from more negative pressure on the inlet side to less negative on the outlet side, maintaining the negative pressure safety feature of the system. The induced draft fans were sized to provide negative pressure throughout the system.

The recirculation fan was manufactured by Twin City Fan and Blower Company. The fan motor was 25 HP and capable of moving 5,800 ACFM of process gas, at 550 °F and 12 inches of water gauge. The recirculation fan was procured with an operational limit of a minimum of 400 °F, and consequently could not be started until the HGDS system had warmed up for some time. The design criteria for the recirculation fan was presented in Table 3.5.

Table 3.5

FAN DESIGN CRITERIA

Location: Denver, Colorado (Adams County)

Temperature: Outdoor winter minimum -10° F   Outdoor winter maximum 70° F

Elevation: 5,300 above sea level
Installation: Indoor ________, exposed to weather ___x___
Environment: Relatively clean ________, dusty ___x___, corrosive ________
Service: ___24___ hrs. per day, ___7___ days per week
Available utilities:
Electric supply: ___480___ volt, ___3___ phase ___60___ hertz

DATA SHEET

REQUIREMENTS DESCRIBED	SPECIFIED VALUE
1. Recirculation fan	
Hot process gas volume (ACFM)	5,800
Fan static pressure (" W.G.)	12
Hot process gas temperature (° F)	550
Volume control	None
Maximum BHP at operating temperature	16.5
2. Induced draft fans (2)	
Hot process gas volume	8,100 ACFM (3,400 SCFM)
Fan static pressure (" W.G.)	30
Hot process gas temperature (° F)	575
Volume Control	Inlet air dampers with pneumatic operators
Maximum BHP at operating temperature	62

A recirculating heat system was selected over a once-through heating system for several reasons. The heat transfer calculations indicated that a once-through heating system would result in an inlet temperature which would exceed the maximum limit for concrete, and would result in a large temperature differential from the inlet to outlet of the ductwork. The recirculation system offset this shortcoming by reducing the required inlet gas temperature.

The recirculation system reduces heat loss by recirculating most of the exhaust gas (and heat), rather than discharging it all. This feature reduces the size and energy consumption of the main burner, with associated capital and operating cost savings. This savings offset the capital cost of the recirculation system.

The recirculation system increases the total mass of heated gas circulating through the pit. This increases the available energy for heating, and the velocity of the gas over the pit floor and walls. Increased hot gas mass and velocity provides more uniform heating of the pit and improved convection heat transfer coefficient.

Recirculation System Control

An operating light and alarm at the MCP indicated on/off operating status. Temperature and pressure were monitored locally at the blower discharge and transmitted for display at the MCP. Flow rate and upward or downward trends at the blower discharge were also displayed at the MCP. The recirculation blower was limited to operation when the pit exhaust was greater than 400 °F. The recirculation flow rate was set by a flow control loop consisting of a mass flow transmitter, flow controller, and control valve. The recycle flow rate and upward and downward trends were displayed at the MCP.

3.2.2.8 Induced Draft Fans

The ID fans were the prime movers of process flow through the fume burner and mixing chamber from the primary containment and from the secondary containment through the carbon filter. The HGDS was designed so that the entire system, including the mustard pit, secondary containment, and process train, was operated under a negative pressure. The ID fans drove the negative pressure for the entire system. The fan design called for the secondary containment area to be maintained at a negative pressure of 0.25 inches of water gauge, and the primary containment to be at a negative pressure of 0.50 inches of water gauge. The negative pressure concept is a safety feature which directs leakage inward to the treatment system, promoting worker safety and environmental protection.

The ID fans were located on the process train immediately before the stack. The design criteria for the ID fans are presented in Table 3.5. The ID fans were manufactured by Twin City Fan and Blower Company. Each fan motor was 100 HP and capable of moving 8,100 ACFM (3,400 SCFM) of process gas, at 575 °F and 30 inches of water gauge. The design specifications required that the noise level at 1 foot from the fans does not exceed 85 dba.

A variable flow rate for the ID fans was required for control of the system pressure, flow throughput, and fume burner residence time. Rectangular industrial grade dampers were placed on the inlet of each ID fan to regulate flow rate.

The two ID fans were each sized to operate the HGDS at 100 percent capacity and operate in parallel. Each fan was of sufficient size to pull the required negative pressure at full flow rate through the system. The ID fans were operated continuously together at 50 percent load, to provide immediate on-line fan operation in the event of the failure of one fan.

<u>Induced Draft Fan Control</u>

An operating light at the MCP indicated operating status, and an alarm indicated motor shutdown due to overload. A hand switch was located at the motor control center. A selector switch at the MCP allowed the operator to run the blowers in automatic or manual modes or to shut them off. Each ID fan was equipped with an inlet damper controlled by a flow control loop, including mass flow transmitter and flow controller. In the event of failure of one fan, the inlet damper would close to prevent short-circuiting around the fan ductwork.

Control of the flow rate for both fans was based on maintaining the negative pressure in the primary containment area. Failure of one ID fan caused the pressure in the primary containment area to become less negative, and the automatic system response opened the other fan damper to compensate for the loss of flow. The second fan ramped up to an increased flow rate to maintain the negative pressure in the primary containment. The control system response to a loss of both ID fans caused all burners to trip, and placed the HGDS in the Contain Mode (described in Section 3.2.3).

<u>Secondary Containment Area Ventilation Control</u>

Ventilation of the secondary containment area was accomplished by pulling air through the carbon filter by the induced draft fans. The rate at which air was exhausted was controlled by a flow control loop consisting of mass flow transmitter, valve positioner, and control valve. A local thermometer and a temperature transmitter monitored the gas temperature going into the carbon filter, which was displayed and trended at the MCP. The flow rate was controlled by a control valve and pneumatic valve positioner which were adjusted to maintain a maximum secondary containment temperature of 130 °F. An alarm was activated if the temperature exceeded 130 °F.

Fresh air for cooling the secondary containment area was introduced through the west containment wall through an adjustable damper to maintain a negative pressure of - 1/4 inches water gauge (WG). The temperature and pressure in the secondary containment area were monitored at the MCP, with trending and high temperature and pressure alarms. Ventilation air temperature at the carbon filter was monitored and trended at the MCP, and an alarm was provided.

A Minicam agent analyzer monitored the agent concentration in the secondary containment area, and relayed this information to the MCP. The MCP displayed concentration (in units Time Weighted Average [TWA]), trends, and alarms. If the agent concentration exceeded 0.1 TWA, the alarm was activated.

3.2.2.9 Stack

The final element of the process system is the stack. Process exhaust from the ID fans was discharged to the atmosphere. The stack was located downstream of the ID fans and is the only equipment in the HGDS under positive pressure. The stack is a 24 inch diameter steel structure, 55 feet high.

The stack was sized based on similar stack heights immediately nearby. Public sensitivity to construction of a new large stack precluded a large structure. Existing nearby stacks from early processes were considered for use in the HGDS, but were rejected because of the potential for bias of results due to entrainment of prior contamination.

Stack/Exhaust System Monitoring

A thermometer was provided mid-height on the stack for direct reading of stack temperature.

Six air quality analyzers and one agent analyzer monitored the exhaust at either the fume burner discharge or the stack using an either/or switch for sampling lines. Separate analyzers monitored hydrocarbon, sulfur dioxide, nitrogen oxides, carbon dioxide, carbon monoxide, and oxygen. The air quality analyzers and agent analyzer normally monitored the fume burner exhaust before the mixing chamber, which provided more accuracy than the stack. These analyzers could be switched to the stack as required. Each of the seven analyzers had a readout at the MCP, and each analyzer was trended. In the event the detected level exceeded a predetermined set point, alarms were activated.

3.2.3 Process Control and Monitoring System

3.2.3.1 Process Control System

The process control system (PCS) permitted remote control and monitoring of the HGDS process. A computer control station located in the control trailer received and displayed process information relayed from HGDS instruments and equipment, as described in Section 3.2.2. Real time operational feedback, such as temperature, pressure, flow, alarm conditions, and equipment operating (on/off) status, were displayed on the Main Control Panel (MCP) at the control station. This information allowed operators to manually control, adjust, and monitor the HGDS remotely from the control station. Automatic control of critical subsystems was provided to instantaneously respond to operating conditions, alarm conditions, or failure scenarios. Manual override of automatic functions permitted manual control when desired.

The operators provided process monitoring and control of the system on the MCP using Control View (Allen Bradley) process control software on two industrial computers, the MCP and a spare. The MCP was an Industrial Model IBM 7546 Computer using the 50/25 MHz 80486SLC2 microprocessor, with IBM 7554 monitor. High speed mass storage was provided by an internal hard disk and 400 MB capacity. Two printers were provided for printing process output, alarms or graphic displays. The printers were Epson LQ-2550, 24 pin, dot matrix units. A Dell 486/33 computer was used as an on-line backup in the event of the primary computer failing. All HGDS adjustments and monitoring were conducted from the MCP. Real-time alarm conditions were printed out next to the MCP to allow for quick response times. The second computer was also useful in allowing the control operator to view two different control screens at the same time. Hence, system responses to control adjustments (e.g., ID fan damper adjustments) could be observed without switching between control screens on one monitor.

System software was driven by Microsoft DOS 5.0 digital operating system. The primary software components were Allen Bradley PLC-5 Programming and Allen Bradley Control view 3000 Core Package with the following features:

- Graphics Package.
- Data Logger Package.
- Trending Package.
- Mouse Package.
- Event Detector Package.
- Alarming Package.

- Diagnostics Package.
- Utilities Package.

Alarm conditions were established at the control station, so that limiting conditions of operation for temperature, pressure, and emissions could be instantaneously recognized.

If primary and secondary power supplies were interrupted, the Uninterruptible Power Supply (UPS) automatically engaged to furnish power to the control station to continue system monitoring for 30 minutes. Remote control of the system operations from the control station was not possible in this event. After the 30 minutes of UPS power had expired, system monitoring was no longer available.

The MCP was hard-wired to two programmable logic controllers (PLCs), one for process control and another for critical safety systems. The PLCs were digital signal processors that controlled electrically operated devices on the HGDS, such as solenoid valves, relays, motor starters, power contactors, and valve positioners. Pneumatic-operated control valves were also actuated by signals from the PLC. Two Allen Bradley PLCs were installed in a NEMA-1 cabinet, which was located in the control trailer. The PLCs were hard wired to the MCP. One was used for process control (PCL-1), while the other was used for the critical safety systems (PLC-2). Process control variables under PLC-1 included pressure transmitters, motor starters, temperature transmitters, flow transmitters, valve operations under the Normal Mode of operation, and air compressor operations. Safety systems controlled under the PLC-2 included pressure switches, natural gas pressures switches and flow control, burner fire eye instrumentation, and valve operations controlling the Backup Mode of operation. More detailed information regarding instrumentation is presented in Section 3.2.3.5.

Pre-programmed instructions were communicated from the PLC to an intelligent input/output (I/O) transfer module. The I/O transfer modules accomplished data transfer by communicating between the PLC and the operational devices. Five I/O cabinets were located throughout the HGDS. System telemetry consisted of 4-20 mA dc analog signals through a hard wire network between the PLC and control and monitoring devices throughout the HGDS. The five I/O cabinets consisted of Allen Bradley hardware and were NEMA-4 rated. Each I/O cabinet was primarily dedicated to a specific piece of equipment. I/O cabinet #1 was dedicated to the thermocouples and located on the east side of Building 537 secondary containment. I/O cabinet #2 was dedicated to the MCC and located within the MCC. I/O cabinet #3 and #4 were primarily dedicated to the main burner and fume burner, respectively, and located in the process area. I/O cabinet #5 was primarily dedicated to the stack and was located next to the stack.

Data recordkeeping was provided on electronic and hard copy records, and included two data recorder/printers, one for normal events and the other for alarm events. Paralleling the process control system was a Data Acquisition System (DAS) connected to a data highway. While the MCP had a limited capacity for data storage, the DAS primarily recorded for historical purposes. The DAS stored and recorded process and emissions information for later evaluation and interpretation, such as calculations of heat and mass balances, fume burner efficiency, and process analysis.

The DAS consisted of a Dell 486/66 computer and was located in the west room of the Control Trailer. The DAS acted as a terminal and read process and monitoring data directly from the Control Station. The computer had a Allen-Bradley Data Highway Card, 1784-KT, installed so that it could be connected to the data highway used for the HGD control system. The DAS operated under Microsoft Windows with the following software: ICOM WinLinx (interface with the Allen-Bradley card), Visual Basic to display the data on the monitor and store the data in a Microsoft Access data format using the Dynamic Data Exchange.

Historical data was archived by the DAS for future review and evaluation. The DAS was operated throughout the heatup and field demonstration. The DAS was programmed to record instrument data at five minute intervals and store the data for future interpretation. The log interval of five minutes was adjustable down to thirty second intervals.

3.2.3.1 Modes of Operation

The instrumentation and control system provided three modes of operation for the HGDS: the Normal Mode, the Backup Mode, and the Contain Mode. The three operating modes are described in further detail as follows.

Normal Mode

The Normal Mode was the mode of operation used during heatup and cooldown of the mustard pit. Discharge of pit exhaust in the Normal Mode occurred through the fume burner primary treatment train. The Normal Mode was intended to meet the primary design criteria of the HGDS for pit temperature and time, and fume burner temperature and residence time. In the Normal Mode, the ventilation air from the secondary containment was treated directly through the carbon filter, and not the fume burner.

Backup Mode

The Backup Mode utilized the radiator/carbon filter treatment train to treat pit exhaust gas in the event of fume burner failure. The ductwork was configured such that the fume burner/mixing chamber exhaust was passed through the radiator to the carbon filter, where it was forwarded by the ID fans to the stack. This arrangement permitted the Backup Mode to be on-line with the fume burner, during ramp-up of the fume burner or if the fume burner temperature dropped below specifications. Ventilation air from secondary containment air was treated directly through the carbon filter unit (not through the radiator).

A process objective for temperature control in the Backup Mode was to reduce the exhaust gas temperature entering the carbon unit to below 130 °F, to protect the carbon medium from excess temperature. To meet this criterion, exhaust gas temperature exiting the fume burner was reduced in the mixing chamber, and then cooled to below 130 °F in the radiator. Temperature in the mixing chamber was automatically controlled by the system Programmable Logic Controller.

Emissions were controlled and treated by passing the exhaust gas through the carbon unit. Adjustments to the amount of blending air and total volume of exhaust gases passing through the carbon unit were made from the control station.

Contain Mode

The Contain Mode was an emergency system response to catastrophic failure of subsystems of the HGDS. When activated, the Contain Mode placed critical automatic valves, such as the exhaust dampers, mixing chamber inlet, and combustion air inlets, in the closed position. The objective was to seal the system from the atmosphere in the event of system-wide failure. The Contain Mode could be activated automatically or manually by operators. Automatic activation of the Contain Mode could occur in the event of failure of all three power supplies. Other failure scenarios for which manual activation of the Contain Mode would be appropriate include failure of both ID fans or failure of both fume burners combined with carbon unit breakthrough. The Contain Mode could only be engaged if all burners and both ID fans were tripped. Fail settings on Contain Mode equipment (valves and dampers) were designed to fail into a Contain Mode configuration.

The operational objective of the Contain Mode was to close all inlet nozzles and exhaust paths exiting the system. No direct exhaust gas emissions should occur during the Contain Mode.

3.2.3.2 Control and Monitoring Locations and Functions

Key control and monitoring points for the system are listed in Table 3.6, including all control valves, and agent and emissions monitors. The location and control function at each of these points is presented. Also, the control configuration for each unit in the three modes of operation (normal, backup, contain) are shown, as well as the backup contingency in the event of failure of each unit.

The automatic (control) valves consisted of Fisher® PosiSeal Model A31A butterfly valves with Bettis® rotary valve actuators. A Moore® positioner and Fisher® filter regulator were mounted on the units. The valves ranged in

TABLE 3.6 CONTROL VALVES, AND EMISSIONS AND AGENT MONITORS, LOCATIONS, AND FUNCTIONS

		VALVE CONFIGURATION IN CONTROL MODE					
DESCRIPTION	TAG NO.	NORMAL MODE	BACKUP MODE	CONTAIN-MENT MODE	LOCATION	CONTROL FUNCTION	FAILURE CONFIGURATION
HGDS PROCESS CONTROL							
Control Valve (14")	TV-400	Open	Open	Closed	Mixing Chamber Cooling Air	Modulates Ambient Air to Mixing Chamber for Temperature Control	Fails-Closed
Control Valve (14")	XV-401	Open	Closed	Closed	Carbon Filter Outlet	Modulates Secondary Containment Air Flow into Mixing Chamber for Temperature Control	Fails-Closed
Control Valve (12")	FV-405	Open	Closed	Closed	Carbon Filter Inlet	Controls Secondary Containment Air Flow into Carbon Unit	Fails-Closed
Control Valve (22")	XV-412	Open	Closed	Closed	Mixing Chamber Outlet	Controls Backup Mode Operations	Fails-Closed
Control Valve (22")	XV-421	Open	Open	Closed	North ID Fan	Controls Flow Through HGDS at North ID Fan	Fails-Closed
Control Valve (22")	XV-422	Open	Open	Closed	South ID Fan	Controls Flow through HGDS at South ID Fan	Fails-Closed
Control Valve (12")	HV-205	Closed	Closed	Closed	Test By-pass Duct	Simulates Pressure Drop in Bypass During Pre-Test Operations	Fails-Closed
Control Valve (22")	XV-402	Closed	Open	Closed	Radiator Outlet	Controls Back-up Mode Operation	Fails-Closed
Control Valve (22")	XV-406	Closed	Open	Closed	Radiator Inlet	Controls Back-up Mode Operation	Fails-Closed
Control Valve (22")	XV-414	Closed	Open	Closed	Carbon Filter Outlet	Controls Back-up Mode Operation	Fails-Closed

TABLE 3.6 CONTROL VALVES, AND EMISSIONS AND AGENT MONITORS, LOCATIONS, AND FUNCTIONS

		VALVE CONFIGURATION IN CONTROL MODE					
DESCRIPTION	TAG NO.	NORMAL MODE	BACKUP MODE	CONTAIN-MENT MODE	LOCATION	CONTROL FUNCTION	FAILURE CONFIGURATION
HOT GAS DISTRIBUTION CONTROL							
Control Valve (16")	FV-204	Open	Closed	Closed	Recirculation Blower	Modulates Recirculation Air Flow	Fails-Closed
Control Valve (12")	HV-206	Open	Closed	Closed	South End of Hot Gas Distribution manifold	Controls Distribution of Hot Gas into South End of Pit	Fails-Closed
Control Valve (12")	HV-207	Open	Closed	Closed	Middle of Hot Gas Distribution Manifold	Controls Distribution of Hot Gas into Middle of Pit	Fails-Closed
Control Valve (12")	HV-208	Open	Closed	Closed	North of Hot Gas Distribution Manifold	Controls Distribution of Hot Gas into North End of Pit	Fails-Closed
MAIN BURNER CONTROL							
Pressure Control Valve (1 1/2")	PCV-100	Open	Closed	Closed	Main Burner Main Natural Gas Supply	Pressure Control of Main Burner Gas Supply. Set Point = 2 psig	Fails-Closed
Pressure Control Valve (1 1/2")	PCV-110	Open	Closed	Closed	Main Burner Main Natural Gas Supply	Pressure Control of Main Burner Gas Supply. Set Point = 1.5 psig	Fails-Closed
Shut-off Valve (1 1/2")	XV-103	Open	Closed	Closed	Main Burner Main Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (1 1/2")	XV-104	Open	Closed	Closed	Main Burner Main Natural Gas Supply	Solenoid Operated Pressure Relief Valve of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-112	Open	Closed	Closed	Main Burner Main Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-113	Open	Closed	Closed	Main Burner Main Natural Gas Supply	Solenoid Operated Pressure Relief Valve of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-114	Open	Closed	Closed	Main Burner Main Natural Gas Supply	Solenoid Operated Flow on/off of Natural gas	Fails-Closed
Control Valve (1 1/2")	FV-106	Open	Closed	Closed	Main Burner Main Natural Gas Supply	Flow Control of Natural Gas	Fails-Closed
Control Valve (4")	FV-125	Open	Closed	Closed	Burner Combustion Air Supply	Flow Control of Combustion Air, with Low and High Position Alarms	Fails-Closed

TABLE 3.6 CONTROL VALVES, AND EMISSIONS AND AGENT MONITORS, LOCATIONS, AND FUNCTIONS

		VALVE CONFIGURATION IN CONTROL MODE					
DESCRIPTION	TAG NO.	NORMAL MODE	BACKUP MODE	CONTAIN-MENT MODE	LOCATION	CONTROL FUNCTION	FAILURE CONFIGURATION
FUME BURNER CONTROL							
Pressure Control Valve (3")	PCV-301	Open	Closed	Closed	Fume Burner Main Natural Gas Supply	Pressure Control of Fume Burner Gas Supply. Set Point = 1.25 psig	Fails-Closed
Pressure Control Valve (3")	PCV-303	Open	Closed	Closed	Fume Burner Igniter Natural Gas Supply	Pressure Control of Fume Burner Pilot Gas Supply, Set Point = 0.25 psig	Fails-Closed
Shut-off Valve (2")	XV-332	Open	Closed	Closed	Fume Burner No. 1 Main Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (2")	XV-333	Open	Closed	Closed	Fume Burner No. 1 Main Natural Gas Supply	Solenoid Operated Pressure Relief Valve of Natural Gas	Fails-Closed
Shut-off Valve (2")	XV-334	Open	Closed	Closed	Fume Burner No. 1 Main Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-337	Open	Closed	Closed	Fume Burner No. 1 Igniter Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-338	Open	Closed	Closed	Fume Burner No. 1 Igniter Natural Gas Supply	Solenoid Operated Pressure Relief Valve of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-339	Open	Closed	Closed	Fume Burner No. 1 Igniter Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (2")	XV-342	Open	Closed	Closed	Fume Burner No. 2 Main Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (2")	XV-343	Open	Closed	Closed	Fume Burner No. 2 Main Natural Gas Supply	Solenoid Operated Pressure Relief Valve of Natural Gas	Fails-Closed
Shut-off Valve (2")	XV-344	Open	Closed	Closed	Fume Burner No. 2 Main Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-347	Open	Closed	Closed	Fume Burner No. 2 Igniter Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-348	Open	Closed	Closed	Fume Burner No. 2 Igniter Natural Gas Supply	Solenoid Operated Pressure Relief Valve of Natural Gas	Fails-Closed
Shut-off Valve (1/2")	XV-349	Open	Closed	Closed	Fume Burner No. 2 Igniter Natural Gas Supply	Solenoid Operated Flow on/off of Natural Gas	Fails-Closed

TABLE 3.6 CONTROL VALVES, AND EMISSIONS AND AGENT MONITORS, LOCATIONS, AND FUNCTIONS

		VALVE CONFIGURATION IN CONTROL MODE					
DESCRIPTION	TAG NO.	NORMAL MODE	BACKUP MODE	CONTAIN-MENT MODE	LOCATION	CONTROL FUNCTION	FAILURE CONFIGURATION
Control Valve (4")	FV-314	Open	Closed	Closed	Fume Burner No. 1 Combustion Air Supply Flow	Control with Low and High Position Alarms for the Fume Burner No. 2 Combustion Air	Fails-Closed
Control Valve (4")	FV-324	Open	Closed	Closed	Fume Burner No. 2 Combustion Air Supply Flow	Control with Low and High Position Alarms for the fume Burner No. 2 Combustion Air	Fails-Closed
Control Valve (2")	FV-336	Open	Closed	Closed	Fume Burner No. 1 Main Natural Gas Supply	Flow Control of Fume Burner No. 1 Natural Gas	Fails-Closed
Control Valve (2")	FV-346	Open	Closed	Closed	Fume Burner No. 2 Main Natural Gas Supply	Flow Control of Fume Burner No. 2 Natural Gas	Fails-Closed
Control Valve (4")	FV-314	Open	Closed	Closed	Fume Burner No. 1 Combustion Air	Controls Combustion Air Flow	Fails-Closed
Control Valve (4")	FV-324	Open	Closed	Closed	Fume Burner No. 2 Combustion Air	Controls Combustion Air	Fails - Closed
AGENT MONITORING:							BACK-UP
Agent Element	AE-201	On-line	On-line	On-line	Secondary Containment	Agent Monitoring & Alarm	DAAMS tubes
Agent Element	AE-360	On-line	On-line	On-line	Primary Containment	Agent Monitoring & Alarm	DAAMS tubes
Agent Element	AE-400	On-line	On-line	On-line	Fume Burner Outlet	Agent Monitoring & Alarm	AE-437 at Stack/ DAAMS tubes
Agent Element	AE-410	On-line	On-line	On-line	Midway in Carbon Filter	Agent Monitoring & Alarm	AE-437 at Stack/ DAAMS tubes
Agent Element	AE-437	On-line	On-line	On-line	Stack	Agent Monitoring & Alarm	DAAMS tubes/Spare Minicam
Agent Element	AE-703	On-line	On-line	On-line	Control Trailer	Agent Monitoring & Alarm	DAAMS tubes/Spare Minicam
Agent Element	AE-710	On-line	On-line	On-line	East Wall of Bldg 537 Outside of Containment	Agent Monitoring & Alarm	DAAMS tubes/Spare Minicam

TABLE 3.6 CONTROL VALVES, AND EMISSIONS AND AGENT MONITORS, LOCATIONS, AND FUNCTIONS

		VALVE CONFIGURATION IN CONTROL MODE					
DESCRIPTION	TAG NO.	NORMAL MODE	BACKUP MODE	CONTAIN-MENT MODE	LOCATION	CONTROL	BACK-UP
EMISSION MONITORING							
Analyzing Indicator	AI-431	On-line	On-line	On-line	On Stack	Hydrocarbon Detection and Low Level Alarm on Stack	EPA Methods Tests
Analyzing Indicator	AI-432	On-line	On-line	On-line	On Stack	SOx Detection and High Level Alarm on Stack	EPA Methods Tests
Analyzing Indicator	AI-433	On-line	On-line	On-line	On Stack	NOx Detection and Low Level Alarm on Stack	EPA Methods Tests
Analyzing Indicator	AI-434	On-line	On-line	On-line	On Stack	CO_2 Detection and High Level Alarm on Stack	EPA Methods Tests
Analyzing Indicator	AI-435	On-line	On-line	On-line	On Stack	CO Detection and Low Level Alarm on Stack	EPA Methods Tests
Analyzing Indicator	AI-436	On-line	On-line	On-line	On Stack	O2 Detection and High Level Alarm on Stack	EPA Methods Tests

size from 4" valves on the combustion air lines to 22" valves on the system discharge lines. Cooling air supplied to the mixing chamber was controlled by two 14" Series Va Technaflow Rovalves® that were designed for operational temperatures of 2,000 °F. The agent and emissions monitors are described in Section 3.2.3.5.

3.2.3.3 System Failure Response

All standard control logic for the instrumentation and control system was developed with safety as the primary objective. Safety issues were the primary drivers for the system startup and operation logic, and for control decisions.

The process control system was designed to automatically respond to failure of critical safety systems during operation of the HGDS. The intent was to have instantaneous response action by the computer control system in the event of a critical process failure. The instantaneous timing of this response was far more desirable than the manual response of an operator to an alarm.

As part of the Preliminary Hazards Analysis, a Failure Modes and Effects Analysis was conducted to examine the control system for potential safety hazards. Several control responses were incorporated into the process control system to address potential safety hazards.

These automatic control responses were programmed into the system, and include:

- One fume burner failure: When one burner was shut down while at normal operating conditions, the other burner automatically took over, maintaining the outlet gas temperature at approximately 2,000 °F.
- Failure of both fume burners: When both fume burners were tripped while operating, automatic transfer to the Backup Mode occurred.
- One ID fan failure: When one ID fan failed with both operating, the other ID fan ramped up to 100% capacity.
- Failure of both ID fans: Upon failure of both ID fans, the system automatically switched to Contain Mode.

- Generator failure: When one generator failed, the system automatically switched to line power.

3.2.3.4 Instrument Air Compressors and Control System Support Equipment

Pneumatic process control devices were actuated by compressed air provided by two air compressors (ACP Model 53V). The compressors were identical 5 horsepower units mounted on 80 gallon receivers, one wet air receiver and one dry air receiver. Total capacity of both compressors was 36.2 ACFM at 120 psig, and a noise level of 81 dba was specified.

Normally one compressor was fully operational, while the other cycled to maintain system pressure at 120 psig. To equalize equipment wear, operational cycles were alternated weekly. The duty compressor was started when the pressure in the wet air receiver dropped to 100 psig and stopped at 120 psig.

The air was treated in a dryer and filter to instrument quality and stored in the dry air receiver. The air dryer/filter consisted of a pre-filter, a regenerative air dryer and post-filter section, to reduce the water content of the compressed air to meet instrument air specifications of -40 °F dew point. The low dew point insured that freezing did not occur in air lines or instruments. The twin dryer towers were self-regenerating and required little or no attention during operation. A small quantity of air was purged from the operational dryer tower and passed through the other tower to dry or recharge the desiccant. Automatic traps discharged accumulated condensate to the atmosphere. Coalescing oil filters removed oil and vapor blowby from the compressors to further improve instrument air quality.

The dry air receiver was an ASME coded vessel designed for 250 psig and stored only instrument quality air from the air dryer/filter. An alarm was activated when pressure fell below 95 psig, and a relief valve protected the receiver by discharging excess air above 125 psig. An electrically timed and operated trap drained condensate accumulated in the receiver.

Each compressor had an on/off switch at the MCP which allowed automatic or manual operation. The compressors pressurized the wet air receiver, which was monitored by a pressure gauge and pressure switch. Pressure in the dry air receiver was monitored by local gauge and was communicated to the MCP. A low pressure alarm and pressure relief valve were provided in the dry air receiver.

3.2.3.5 Instrumentation

Design Considerations

The primary criteria for the instrumentation and control system for the HGDS was high reliability and reasonable cost. The added expense of a fully redundant system was avoided, in part by limiting procurement to known suppliers of high quality equipment. A measure of redundancy was provided by direct measuring field instruments at some locations, which duplicate remote transmitting instruments. For example, a local field pressure gauge was mounted in close proximity to a pressure transmitter, which sent the same pressure data to the control trailer.

A complete listing of process instrumentation is presented in Table 3.7, which includes their location and function.

Temperature Monitoring in Pit Structure

Thermocouples were placed into the concrete of the pit to monitor the temperature profile and heat-up rate. These units were Type K, and were 304 stainless steel sheath, 1/16 inch diameter by 24 inches long and ungrounded junctions manufactured by Marlin Manufacturing Corporation. The thermocouple had a Marlox high temperature transition junction connecting the extension wire to the thermocouple element. The thermocouples were calibrated to NIST traceable references and were used to verify that materials reached the temperature objective of 350 °F in the pit.

To monitor the temperature profile in the pit, the thermocouples were arranged to monitor the inner surface, middle, outer surface, and soil. This was accomplished by positioning the thermocouples in an assembly grouted into holes drilled into the pit floor and walls. The grout assemblies consisted of two types. The first consisted of two thermocouples to monitor only the outside concrete surface. The second consisted of five thermocouples; one for the inner surface, middle, and soil, and two for the outer surface. Ten

TABLE 3.7 INSTRUMENTATION SCHEDULE INCLUDING LOCATIONS AND FUNCTIONS

DESCRIPTION	TAG NO.	LOCATION	FUNCTION
MAIN BURNER SYSTEM			
Pressure Transmitter	PIT-101	Main Burner Main Natural Gas Supply	Pressure Remote Monitoring, and Low and High Pressure Alarms.
Pressure Transmitter	PIT-111	Main Burner Pilot Natural Gas Supply	Pressure Monitoring of Natural Gas Supply.
Pressure Transmitter	PIT-124	Main Burner Combustion Air	Differential Pressure Monitoring. of
Pressure Indicator	PI-100	Main Burner Main Natural Gas Supply	Pressure Monitoring Visual Backup to PIT-101.
Pressure Indicator	PI-110	Main Burner Pilot Natural Gas Supply	Pressure Monitoring Visual Backup to PIT-111.
Pressure Indicator	PI-115	Main Burner Pilot Natural Gas Supply	Pressure Monitoring Visual Backup Redundancy.
Pressure Indicator	PI-116	Main Burner Pilot Natural Gas Supply	Pressure Monitoring Visual Backup Redundancy.
Pressure Indicator	PI-123	Main Burner Combustion Air	Pressure Monitoring Visual Backup to PIT-124.
Pressure Switch	PSLL-102	Main Burner Main Natural Gas Supply	Pressure Switch and Alarm for Low Level Natural Gas Pressure.
Pressure Switch	PSHH-107	Main Burner Main Natural Gas Supply	Pressure Switch and Alarm for High Level Natural Gas Pressure.
Pressure Switch	PSHH-115	Main Burner Pilot Natrual Gas Supply	Pressure Switch and Alarm for High Level Natural Gas Pressure.
Temperature Transmitter	TT-108	Main Burner Hot Gas Output	Remote Temperature Monitoring of Air Into Pit, with High and High-High Alarms.
Temperature Transmitter	TT-109	Main Burner Hot Gas Output	Remote Temperature Redundant Monitoring of Air into Pit, with High and High-High Alarms
Temperature Transmitter	TT-122	Main Burner Combustion Air	Temperature Monitoring of Air to Main Burner.
Temperature Indicator	TI-107	Main Burner Shroud Assembly	Visual Temperature Indicator of Main Burner Shroud Assembly.
Mass Flowmeter	FE-106	Main Burner Main Natural Gas Supply	Remote Mass Flow Measurements of Natural Gas into Main Burner.
Mass Flowmeter	FE-125	Main Burner Combustion Air	Mass Flow Measurements and Low and High Flow Alarms of Combustion Air into Main Burner.

TABLE 3.7 INSTRUMENTATION SCHEDULE INCLUDING LOCATIONS AND FUNCTIONS

DESCRIPTION	TAG NO.	LOCATION	FUNCTION
Burner Fireye	BE-108A	Main Burner Assembly	Remote Indicator of a Flameout.
Burner Fireye	BE-108B	Main Burner Assembly	Remote Indicator Redundancy of a Flameout.
Operation Alarm	OA-121	Main Burner Combustion Air Blower	Alarm Condition if Motor is not Operating.
<u>RECIRCULATION BLOWER SYSTEM</u>			
Pressure Transmitter	PIT-202	Recirculation Return Gas	Differential Pressure Monitoring of Return Gas.
Pressure Transmitter	PIT-207	Primary Containment	Differential Pressure Monitoring with High and Low Pressure Alarms of Primary Containment.
Pressure Transmitter Pressure	PIT-208	Primary Containment	Differential Pressure Monitoring Redundancy with High and Low Alarms of Primary Containment.
Pressure Transmitter	PIT-211	Secondary Containment	Differential Pressure Monitoring with Low and High Alarms of Secondary Containment.
Pressure Transmitter	PIT-212	Secondary Containment	Differential Pressure Monitoring with Low and High Pressure Alarms Redundancey of Secondary Containment.
Pressure Indicator	PI-201	Recirculation Return Gas	Pressure Monitoring Visual Backup to PIT-202.
Temperature Transmitter	TT-200-X	Pit Thermocouples	Pit Thermocouple Temperature Monitoring with High and High-High Temperature Gradient Alarms.
Temperature Transmitter	TT-202	Recirculation Return Gas	Temperature Monitoring of Return Gas Air.
Temperature Transmitter	TT-207	Primary Containment	Temperature Monitoring with High and High-High Alarms of Primary Containment.
Temperature Transmitter	TT-208	Primary Containment	Temperature Monitoring with High and High-High Alarms of Primary Containment.
Temperature Transmitter	TT-211	Secondary Containment	Temperature Monitoring with High Alarm of Secondary Containment.
Temperature Transmitter	TT-212	Secondary Containment	Temperature Monitoring with a High Alarm of Secondary Containment.

TABLE 3.7 INSTRUMENTATION SCHEDULE INCLUDING LOCATIONS AND FUNCTIONS

DESCRIPTION	TAG NO.	LOCATION	FUNCTION
Temperature Indicator	TI-201	Recirculation Return Gas	Visual Temperature Monitoring in Case of TT-202 Failure.
Mass Flowmeter	FE-204	Recirculation Return Gas	Mass Flow Measurements and High Alarm of the Return Gas.
Operation Alarm	OA-201	Recirculation Fan	Alarm Condition if Motor is not Operating.
FUME BURNER SYSTEM			
Pressure Transmitter	PIT-302	Fume Burner Main Natural Gas Supply	Pressure Monitoring with Low and High Pressure Alarms of Fume Burner Natural Gas Supply.
Pressure Transmitter	PIT-304	Fume Burner Pilot Natural Gas Supply	Pressure Monitoring with a High Alarm of the Igniter Natural Gas Supply.
Pressure Transmitter	PIT-312	Fume Burner No. 1 Combustion Air	Pressure Monitoring with Low Alarm for the Combustion Air.
Pressure Transmitter	PIT-322	Fume Burner No. 2 Combustion Air	Pressure Monitoring with a Low Alarm for Combustion Air.
Pressure Transmitter	PIT-355	Fume Burner Chamber	Pressure Monitoring with Low and High Alarms for the Fume Burner Chamber.
Pressure Indicator	PI-301	Fume Burner Main Natural Gas Supply	Visual Pressure Monitoring of Natural Gas Supply.
Pressure Indicator	PI-303	Fume Burner Pilot Natural Gas Supply	Visual Pressure Monitoring of Natural Gas Supply.
Pressure Indicator	PI-310	Fume Burner No. 1 Combustion Air	Visual Pressure Monitoring of Combustion Air Supply.
Pressure Indicator	PI-320	Fume Burner No. 2 Combustion Air	Visual Pressure Monitoring of Combustion Air Supply.
Pressure Indicator	PI-335	Fume Burner No. 1 Natural Gas Supply	Visual Pressure Monitoring of Natual Gas Supply.
Pressure Indicator	PI-345	Fume Burner No. 2 Natural Gas Supply	Visual Pressure Monitoring of Natual Gas Supply.
Pressure Switch	PSHH-305	Fume Burner Pilot Natural Gas Supply	Pressure Switch and High Alarm for the Igniter Natural Gas Pressure.
Pressure Switch	PSLL-331	Fume Burner No. 1 Natural Gas Supply	Pressure Switch and Alarm for Low-Low Natrual Gas Pressure.
Pressure Switch	PSLL-341	Fume Burner No. 2 Natural Gas Supply	Pressure Switch and Alarm for Low-Low Natural Gas Pressure.
Pressure Switch	PSHH-335	Fume Burner No. 1 Natural Gas Supply	Pressure Switch and Alarm for High-High Level Natural Gas Pressure.

TABLE 3.7 INSTRUMENTATION SCHEDULE INCLUDING LOCATIONS AND FUNCTIONS

DESCRIPTION	TAG NO.	LOCATION	FUNCTION
Pressure Switch	PSHH-345	Fume Burner No. 2 Natural Gas Supply	Pressure Switch and Alarm for High-High Level Natural Gas Pressure.
Temperature Transmitter	TT-311	Fume Burner No. 1 Combustion Air	Temperature Monitoring of Combustion Air.
Temperature Transmitter	TT-321	Fume Burner No. 2 Combustion Air	Temperature Monitoring of Combustion Air.
Temperature Transmitter	TT-354	Fume Burner Chamber	Temperature Monitoring in Fume Burner Chamber.
Temperature Transmitter	TT-355	Fume Burner Chamber	Temperature Monitoring with Low and High Alarms for the Fume Burner Chamber.
Temperature Indicator	TI-351	Fume Burner Chamber	Local InstrumentVisual Temperature Monitoring of Fume Burner Chamber.
Mass Flowmeter	FE-314	Fume Burner No. 1 Combustion Air	Mass Flow Measurements with Low and High Alarms of the Combustion Air.
Mass Flowmeter	FE-324	Fume Burner No. 2 Combustion Air	Mass Flow Measurements with Low and High Alarms of the Combustion Air.
Mass Flowmeter	FE-336	Fume Burner No. 1 Natural Gas Supply	Mass Flow Measurements of the Natural Gas Supply.
Mass Flowmeter	FE-346	Fume Burner No. 2 Natural Gas Supply	Mass Flow Measurements of the Natural Gas Supply.
Burner Fireye	BE-330A	Fume Burner No. 1	Remote Indicator of a Flameout.
Burner Fireye	BE-330B	Fume Burner No. 1	Remote Indicator Redundancy of a Flameout.
Burner Fireye	BE-340A	Fume Burner No. 2	Remote Indicator of a Flameout.
Burner Fireye	BE-340B	Fume Burner No. 2	Remote Indicator Redundancy of a Flameout.
Operation Alarm	OA-310	Fume Burner No. 1 Combustion Air	Alarm Condition if Motor is not Operating.
Operation Alarm	OA-320	Fume Burner No. 2 Combustion Air	Alarm Condition if Motor is not Operating.

TABLE 3.7 INSTRUMENTATION SCHEDULE INCLUDING LOCATIONS AND FUNCTIONS

DESCRIPTION	TAG NO.	LOCATION	FUNCTION
CARBON FILTER/RADIATOR SYSTEM			
Pressure Transmitter	PDIT-410	Carbon Filter Inlet and Outlet	Differential Pressure Measurements and High and High-High Alarms Through the Carbon Filter.
Pressure Indicator	PI-401	Radiator Inlet	Visual Pressure Monitoring of Radiator Inlet.
Pressure Indicator	PI-404	Radiator Outlet	Visual Pressure Monitoring of Radiator Outlet.
Pressure Indicator	PI-405	Carbon Filter Inlet	Visual Pressure Monitoring of Carbon Filter Inlet.
Pressure Switch	PSH-415	Carbon Filter Outlet	Pressure Switch and Alarm for High Level Pressue in the Carbon Filter Outlet.
Temperature Transmitter	TT-400	Mixing Chamber Outlet	Temperature Monitoring of Mixing Chamber Outlet.
Temperature Transmitter	TT-402	Radiator Inlet	Temperature Monitoring and High Alarm of Radiator Inlet.
Temperature Transmitter	TT-403	Radiator Outlet	Temperature Monitoring and High Alarm of Radiator Outlet.
Temperature Transmitter	TT-409	Carbon Filter Inlet	Temperature Monitoring and High Alarm of Carbon Filter Inlet.
Temperature Indicator	TI-401	Radiator Inlet	Visual Temperature Redundancy to the Radiator Inlet.
Temperature Indicator	TI-404	Radiator Outlet	Visual Temperature Redundancy to the Radiator Outlet.
Temperature Indicator	TI-408	Carbon Filter Inlet	Visual Temperature Redundancy to the Carbon Filter Inlet.
Mass Flowmeter	FE-405	Secondary Containment Outlet	Mass Flow Measurements and Low Alarm of Secondary Containment Air.
EXHAUST SYSTEM			
Temperature Indicator	TI-434	On Stack	Visual Temperature Monitoring.
Mass Flowmeter	FE-421	North Induced Draft Fan Outlet	Mass Flow Measurements of North Induced Draft Fan Outlet.
Mass Flowmeter	FE-422	South Induced Draft Fan Outlet	Mass Flow Measurments of South Induced Draft Fan Outlet.
Operation Alarm	OA-421	North Induced Draft Fan Motor	Alarm Condition if Motor is not Operating.
Operation Alarm	OA-422	South Induced Draft Fan Motor	Alarm Condition if Motor is not Operating.

TABLE 3.7 INSTRUMENTATION SCHEDULE INCLUDING LOCATIONS AND FUNCTIONS

DESCRIPTION	TAG NO.	LOCATION	FUNCTION
INSTRUMENT AIR COMPRESSORS AND MISCELLANEOUS EQUIPMENT			
Operation Alarm	OA-601	Air Compressor No. 1	Alarm Condition if Compressor is not Operating.
Operation Alarm	OA-602	Air Compressor No. 2	Alarm Condition if Compressor is not Operating.
Pressure Switch	PSHL-603	Wet Air Receiver	Pressure Switch and Alarm for High and Low Level Pressure in the Wet Air Receiver.
Pressure Indicator	PI-603	Wet Air Receiver	Visual Pressure Indicator.
Pressure Safety Valve	PSV-603	Wet Air Receiver	Relief Valve for High Pressure.
Pressure Indicator	PI-605	Dry Air Receiver	Visual Pressure Indicator.
Pressure Safety Valve	PSV-605	Dry Air Receiver	Relief Valve for High Pressure.
Pressure Switch	PSL-606	Dry Air Receiver	Pressure Switch and Low Level Alarm for System Supply Air.
Pressure Transmitter	PIT-607	Instrument Air Outlet	Pressure Monitoring and Low Level Alarm of Instrument Air Outlet.
Pressure Transmitter	PIT-701	Generator No. 1	Pressure Monitoring and Low Level Alarm of Generator Lube Oil.
Pressure Transmitter	PIT-702	Generator No. 2	Pressure Monitoring and Low Level Alarm of Generator Lube Oil.

assemblies were placed in the floor and east wall with eight in the west wall. Two were placed in the south wall. The placement is shown in Figure 3.4.

Agent Monitoring

Eight chemical agent monitors called Miniaturized Chemical Agent Monitoring system (Minicams) were located around the process system to monitor the stack emissions, unit process effectiveness, and the ambient workplace. The Minicam is a portable near real-time (NRT) gas chromatograph (GC) with detection, recording, and alarm capabilities. The Minicams were provided with a data acquisition and recording system to document results. The Minicams were located specifically for worker and public safety, and environmental protection.

In addition to the Minicams monitoring units, the following equipment was used to perform the NRT mustard agent monitoring:

- A MiniNet data collection system
- Stack sampling kit
- Two single and one four-track strip chart recorders
- Insulated heated sampling lines
- A four unit common gas manifold supply system.

The Minicams were interfaced with a mininet which is a computer link to consolidate data storage, concentration reports, and system operational data at a central host computer location. The Minicams used during the field test were field model FM-1001A with a standard flame photometric detector manufactured by CMS Research Corporation. The Minicam is designed to screen air samples for chemical warfare agents and related compounds. The Minicams is a short (15 meter) column GC equipped with Flame Photometric Detector (FPD). The system operates by drawing a gas sample through either a heated sampling line or directly into an inlet portal where it is adsorbed upon the pre-concentrator tube (PCT). Following a three to five minute sampling time, the inlet portal is closed and the PCT Tube is heated to approximately 200 °C. The volatilized air stream is drawn through the GC column where compound separation occurs. Upon elution from the column, the sample enters the FPD

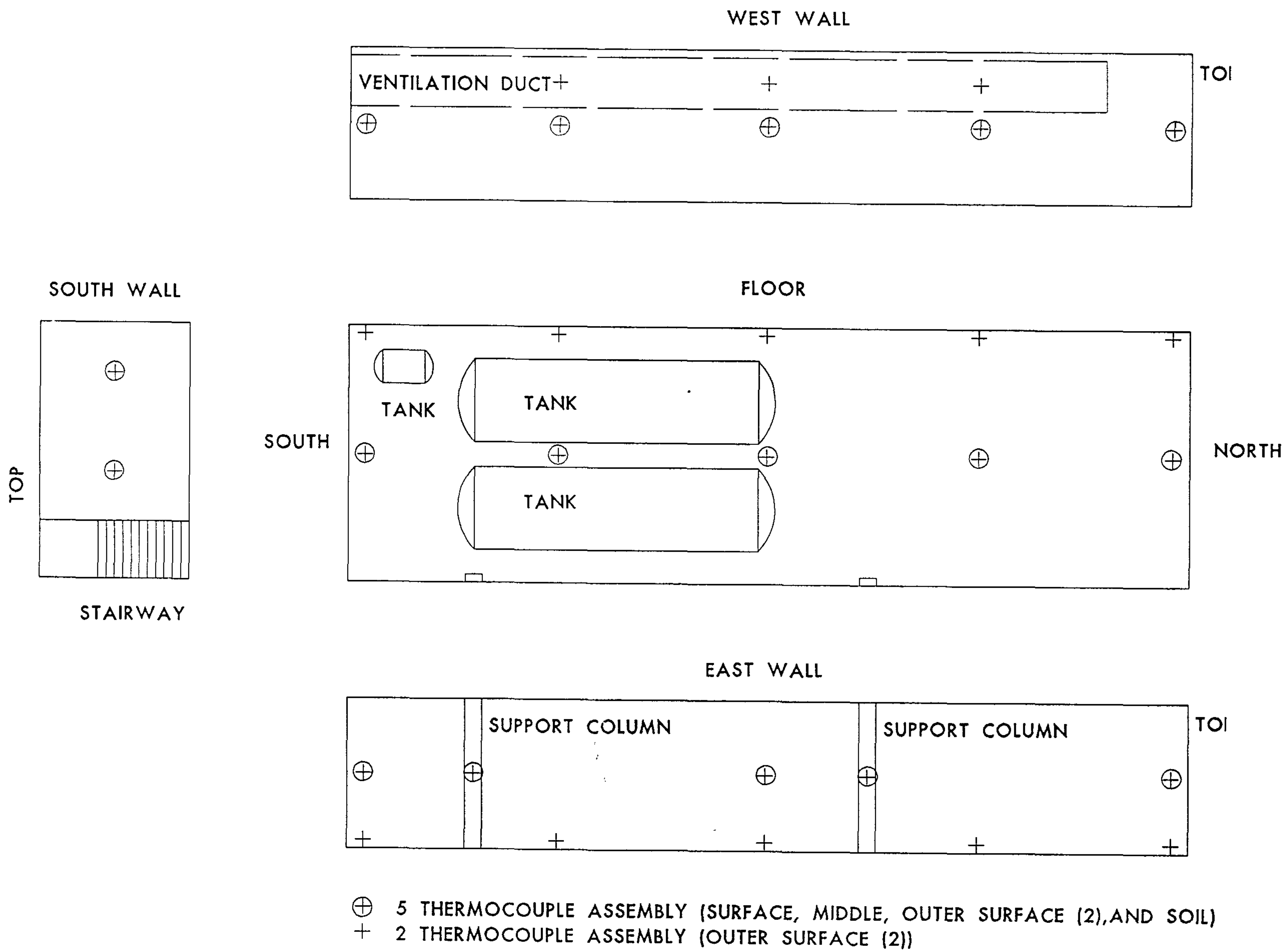


Figure 3.4 - Thermocouple Locations in Mustard Pit

unit where either sulfur or phosphorous is detected (depending upon the detection window). The FPD produces a electrical signal corresponding to the amount of sulfur or phosphorous present in the sample. The signal is converted into a chromatogram which records the elution time of the analyte from the column, the signal strength and duration as retention time, peak height and peak area.

The field Minicams model was selected for this application, and affords the same sensitivity and selectivity as the laboratory model. The field Minicams is equipped with a rugged integral detector and microprocessor, vacuum pump and gas cylinders, encased in a hardened shell which is sealed against moisture.

For monitoring of hot process gas, a Minicams stack sampling systems (MSSS) was required. The MSSS units were installed at the fume burner inlet, the fume burner outlet and stack monitoring locations. The MSSS system allows the individual Minicams to monitor heated air streams for mustard agent while preventing water vapor condensation in the sampling lines or the Minicams.

The data generated by the Minicams was collected on the MiniNet data collection system, connected to the individual Minicams by coaxial cable. The MiniNet collects readings from each instrument and serves as an alarm system. Through the MiniNet, HGDS operators observed data from each Minicam and remotely monitored current conditions at each sampling location without the personal exposure risk. Data from the MiniNet was downloaded daily onto electronic diskette for storage and safekeeping. For redundancy, strip chart recorders logged the analog chromatogram data from each instrument for the purpose of analyzing calibration injections, reviewing interferant peaks and general observation of output.

Figure 3.1 is the process flow diagram for the HGDS which graphically depicts the Minicam locations during the field demonstration. Minicams locations are indicated by the abbreviation "AE", for "Agent Element". The Minicams monitored selected stations in HGDS process system and the environment in containment areas during the entire field demonstration. Seven Minicams were purchased to provide NRT coverage at six locations, with the seventh unit designated as shelf spare. Two additional units were provided by the operations contractor. Table 3.8 lists the Minicams locations by station number.

Placement of Minicams was selected based upon the type of process or safety information required. The locations provide either an "in-line" assessment of the process conditions or ambient conditions inside and outside containment areas. The Minicams provide a quantitative assessment of the HD-related vapors off-gassed from the mustard pit, the effectiveness of the fume burner for destruction of HD and HD byproducts, and the amount of HD-related vapors in stack emissions. Additionally, the Minicams stations provided information concerning monitoring to assure personnel safety. The Minicams were calibrated such that the worker permissible exposure limit of 0.003 mg/m^3 for mustard registered as 1.0 unit Time Weighted Average (TWA) on the Minicams. The Minicams alarms were set at 0.1 TWA (0.0003 mg/m^3).

TABLE 3.8 MINICAMS SAMPLING STATION DESCRIPTION

Station Number	Description of Sampling Location
Minicams Station 1	DAS/Control Trailer Interior
Minicams Station 2	Fume Burner Inlet
Minicams Station 3	Fume Burner Outlet
Minicams Station 4	Secondary Containment Zone (carbon filter inlet)
Minicams Station 5	Carbon Filters
Minicams Station 6	Stack Discharge
Minicams Station 7 & 8	East and West sides of secondary containment

The detailed locations and functions of the eight Minicams are as follows:

(1) Inside the control trailer to monitor the worker area.

(2) Inside the duct leading to the fume burner. This sensor monitored levels of HD being released as the pit was heated.

(3) The juncture of the fume burner outlet and the mixing chamber inlet, prior to being cooled. This point allowed monitoring of the fume burner exhaust.

(4) Inside the duct from the secondary containment area to the carbon filter. This sensor identified leakage from the primary enclosure into the immediately surrounding environment and for releases in the secondary containment area.

(5) Within the carbon filter between the two banks. This helped establish the efficiency of the filter over time, and monitored for the potential breakthrough of the carbon filter.

(6) At the stack. This sensor provided back up and monitored all process emissions before discharge to the environment.

(7) & (8) Outside the secondary containment to the east and to the west to monitor ambient air.

A shelf spare Minicams was provided in case of failure of a unit.

Emission Monitors

Continuous emission monitors were used to measure the levels of gaseous emissions coming from the fume burner and stack. There were three continuous emissions sampling locations. These were at the inlet to the fume burner, the exit of the fume burner, and at the stack. The continuous emission monitoring (CEM) instruments used are listed in Table 3.9. Hydrocarbons (HC) were monitored at the inlet to the fume burner, and the remaining substances (oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen oxides (NO_x)) were monitored at the exit of the fume burner before the mixing chamber. The continuous emission monitors measured gaseous emissions on a full-time basis.

An ice bath condenser was used to reduce moisture to the gas analyzers. The moisture interferes with the operation of the non-dispersive infrared (NDIR) and oxygen analyzers. The gas is not bubbled through water so the impact on the monitoring of hydrocarbons (volatile), sulfur dioxide and NOx is minor based on past sampling activities on similar systems.

TABLE 3.9 CONTINUOUS EMISSION MONITORS

Species	Make	Model	Type
O_2	Servomax	570	Paramagnetic
CO_2	Horiba	VIA-510	NDIR
CO	Horiba	VIA-510	NDIR
SO_2	Horiba	VIA-510	NDIR
NO_X	Horiba	CLA-510	Chemiluminescence
HC	Beckman	400A	FID

3.2.4 Mechanical Design Considerations

Hot Gas Inlet Ductwork

The Hot Gas inlet manifold and distribution system was insulated up to the primary containment to contain heat. Three downcomers from the inlet manifold distributed hot gas into the pit and were provided with remote control valves to direct hot gas to selected areas of the pit. Stainless steel flexible hose was used to direct the hot inlet gas into the two tanks in the pit to ensure heating and circulation in these tanks.

Exhaust Ductwork

Slotted rectangular duct was custom-fabricated for the exhaust ductwork to promote uniform heat distribution and to discourage short-circuiting. The exhaust duct was insulated outside of primary containment to reduce cooling and condensation in the exhaust duct, to reduce heating of secondary containment and to retain heat in the recirculation system.

Cold Bypass Duct

A cold bypass pipe was constructed into the system to provide a means for checkout and testing of equipment and systems without heatup of the mustard pit. The bypass line was located between the main burner discharge and the fume burner inlet, circumventing the pit inlet manifold. A spectacle blind was placed in the pit inlet manifold to isolate the pit during system testing. The spectacle blind and bypass pipe were physically located inside secondary containment. Manual removal of the spectacle blind was required to open the pit inlet manifold. The spectacle blind was included in the system as a fail-safe feature to preclude the heatup of the pit during pre-operational testing (due to operator error).

A control valve was placed in the bypass pipe to simulate the losses in the mustard pit during systemization testing. During pre-operational tests, an 8-inch nozzle was cut into the bypass system to simulate in-leakage of ambient air into the pit during use of the bypass.

3.2.5 Structural Design Considerations

A primary safety requirement of the HGDS was to maintain the structural integrity of the surrounding building. After the HGDS was completed, the facility could then be mothballed, reused, or demolished using conventional demolition techniques. To accomplish this goal, the materials of construction of the building structure had to withstand HGDS process temperatures up to a maximum 750 °F, and a calculated maximum temperature gradient of 200 °F per foot across any concrete structural member or element. Detailed structural calculation and computer modeling were performed to verify that structural integrity would be upheld during the performance of the HGDS under these conditions. Structural analysis of existing concrete elements in Building 537 and the mustard pit revealed a potential for structural deformations under temperature loadings up to 550 °F. These deformations (movements) were calculated to be on the order of 1/2" to 1" for the concrete columns and wall elements which support Building 537 on the east side of the tank pit. While the movements induced additional forces and moments within the existing structural concrete elements, they were not large enough to exceed the capacity of those elements.

The field demonstration included two containment barriers around the mustard pit to prevent the escape of off-gases and minimize heat loss. The primary containment was placed over the top of the pit and consisted of prefabricated modular steel panels, with an outer lining of high temperature ceramic fiber insulation. The panels were joined to form a temperature-resistant structural cover and end walls.

The roof, north, south and east walls of Building 537 were repaired and sealed to create the secondary containment barrier. The west wall of the secondary containment and the recirculation fan secondary containment room were constructed of gypsum wallboard supported with light-gauge metal studs. A synthetic rubber membrane draped on the outside sealed the west containment wall. The primary and secondary containment structures were designed for structural stability, fire resistance, and containment effectiveness during construction and operation of the HGDS, when subjected to high temperatures and pressure loads.

The east wall of the pit is load-bearing, and supports the east wall of Building 537. Two columns, which are an integral part of the east pit wall, are structural bearing columns supporting the building roof. The east pit wall is approximately 12 inches thick, while the columns are 18 inches thick.

The structural load-bearing nature of the east pit wall created a limiting condition of operation for the heatup and cooldown of the HGDS. The limiting factor is the rate of differential expansion of the concrete and rebar over its depth during heatup or cooldown, which could cause substantial cracking or failure of the concrete if uncontrolled. The concrete is limited to a calculated maximum differential temperature of 200 °F per foot of concrete through its depth.

Primary Containment Construction

The function of the primary containment was to provide containment of the mustard pit and a heat barrier between the pit and secondary containment. Also, primary containment served as a negative pressure barrier between the pit and secondary containment.

Primary containment was constructed of steel panels and insulation board, supported by a steel structure. Construction safety and support of the primary containment were main considerations in the design. The containment structure was designed to support the load of several workers during construction. The steel panels were sized to allow two workers to readily handle and install them. A steel support structure was designed to support the panels and installers during construction.

The design criteria for the primary containment structure included the ability to withstand a negative pressure of -1/2 inch of water gauge and temperature of 550 °F. Negative pressure in the primary containment was driven by the induced draft fans through the fume burner exhaust system. For safety reasons, the pressure balance was designed such that pressure was more negative in the primary than secondary containment, and off-gas flowed from secondary to primary containment. To control negative pressure balance, the primary containment was sealed from the secondary containment by a gasket seal which allowed some leakage from secondary containment into primary.

Completion of the primary containment required additional heat barriers at several locations including:

- The north end stairwell.
- The south end stairwell.
- The adjacent ventilation tunnel west of the pit.
- The upper 3 feet of the east pit wall.

The stairwells at the north and south ends of the pit were purposely not included in the target area of the field demonstration. This was because they were not suspected to be contaminated, and their large mass and odd geometric shape created difficult and costly heat transfer problems. The primary containment barriers at the stairwells were constructed of sheet metal and metal studs covered with insulation, to close off the pit from both stairwells and contain the heat in the pit.

The ventilation tunnel on the western side of the west pit wall required additional insulation to complete the primary containment. Insulation board (identical to the primary containment) was pinned to the east wall of the ventilation tunnel to retard heat radiation toward the tunnel and unload booths.

Also, the east pit wall was exposed about 3-feet above ground level on the east side. Similar to above, insulation board was pinned to the top of the east wall of the east pit wall above ground level to provide a heat barrier.

The floor and walls of the pit were not tightly sealed to allow in-leakage from the surrounding ground, to control volatilized off-gas from areas immediately outside the pit. Potential off-gases would subsequently be controlled and treated in the fume burner system.

Plenum and Support Structure

The inlet hot gas was distributed through an inlet manifold and three downcomers into a plenum, which directed the hot air at the pit walls and floor. The plenum was a steel sheet structure which followed the contour of the pit wall and floor, to create an annular space between the pit surface and plenum wall.

The purpose of the plenum was to direct the heat to the walls and floor of the pit, which were the target of the decontamination process. A significant economy of size and energy cost in the main burner system was realized by the use of a plenum, as opposed to pouring the inlet heat into an open pit. The function of the plenum was to increase the velocity of the inlet gas over the pit floor and walls. Increased gas mass and velocity provided more uniform heating of the pit structure and enabled concentration of heat to localized areas with deep cross-sections. Increased velocity provided an improved convection heat transfer coefficient and reduced gas channeling.

The plenum floor was constructed of steel plate, and the plenum walls of steel plate and corrugated steel. Plenum floor plates were tack-welded and supported by fire brick, while the plenum walls were supported by the steel structure. A clearance of 2 to 3 inches was provided between the plenum wall and pit wall to allow for expansion of the support structure during heatup.

Secondary Containment Construction and Location

Secondary containment around the mustard pit was designed to contain off-gas from the pit and surrounding area during heatup, such that hazardous emissions did not escape. The secondary containment was constructed to enclose areas adjacent to the mustard pit which were suspected to be contaminated based on their historical use. This includes the four unload booth locations, where mustard agent was transferred from ton containers to the bulk tanks in the pit, and the sub-floor ventilation ducts and tunnels.

Negative pressure in the secondary containment was driven by the induced draft fans through the carbon filter treatment system. The primary design criteria for inside secondary containment were a minimum negative pressure of -0.25 inches of water gauge (W.G.) relative to atmospheric pressure, and a maximum temperature of 120 °F.

The simplest and most cost-effective construction utilized the existing building walls and roof for secondary containment, as much as practical. The walls were sealed with grout and caulk, and penetrations and openings were closed with block construction.

A temporary wall was constructed on the west side of the pit area to form the west side of the secondary containment. The wall was constructed of double-layered gypsum wall board over metal studs. A hypalon membrane was placed over the west containment wall to further seal containment. The west containment wall was located approximately 16 feet west of the west pit wall. This location was selected to encompass the four unload booth locations and underfloor ventilation tunnels which were known to be contaminated.

Two doorways were placed in the secondary containment walls to permit access during construction. No access was permitted to secondary containment during normal operation. A gravity intake louver was provided in the west containment wall inside Building 537 to ventilate the secondary containment with outside air.

3.2.6 Civil Design Considerations

Site Selection/Site Investigations

The USAEC selected the mustard pit at Building 537 for the Field Demonstration of the Hot Gas Decontamination System after extensive evaluation of alternative sites. Site-specific design considerations at the Building 537 site are addressed here.

A Groundwater Assessment was conducted which examined historical monitoring well data at the site. This assessment concluded that groundwater at the site was sufficiently below the lowest point in the mustard pit not to effect the performance of the field demonstration. The Groundwater Assessment concluded that groundwater was at its lowest point in winter months, further reinforcing the decision to operate the field demonstration in winter.

Utilization of Existing Facilities

In the interest of cost savings, existing facilities were utilized for shelter of support equipment with permission of PMRMA. This includes use of Building 538A for minicam shelter, Building 539 for shelter of the Uninterruptible Power Supply, Building 527 for worker break room, and Building 541 for welding shop and receiving/storage warehouse. No existing RMA process equipment (pipe, blowers, or stacks) was utilized in the HGDS, to eliminate any risk of biasing test results.

Site-Specific Design Considerations

Existing buildings, interferences, electrical lines, and suspected contaminated areas were noted during the site inspections conducted during the early design phase. Efforts were made to minimize the impact of the project on existing structures and surrounding area. The purpose was to provide a design that promotes safe and efficient construction, operation, and removal of the HGDS.

Facility drawings were requisitioned to develop base site plans for superposition of HGDS structures and equipment. Very old drawings (approximately 50 years old) were furnished by PMRMA. A transit survey was conducted of outdoor areas to verify that as-built conditions matched the drawings. At the time, health and safety restrictions precluded the conduct of a transit survey of indoor facilities. The outdoor transit indicated that as-built conditions varied significantly from the antiquated drawings. In the case of outdoor HGDS facilities, project design drawings were modified to accommodate the as-built survey results. In the case of indoor HGDS facilities, a significant amount of field engineering and field changes were later required to accommodate the as-built conditions as they were encountered during construction.

Retrofit of the HGDS at an antiquated manufacturing plant that is surrounded with suspected contamination created special design conditions. Many design and construction considerations were made to allow for this circumstance, which contributed to the cost of construction and operation.

<u>Mustard Pit</u>

The mustard pit was the pre-determined target of the Hot Gas Decontamination effort. The mustard pit is a 16 foot wide by 51 foot long sub-basement in Building 537, with concrete floors and walls.

The concrete floor of the mustard pit varies in thickness from 8 to 17 inches. The original floor was covered over with new concrete pours at least twice, to encapsulate contamination from former mustard spill incidents. Core sampling indicated that the thickness of each pour varied from 1 to 7 inches. The floor slopes gently to a sump located in the southwestern corner of the pit. The sump is approximately 14 inches by 20 inches by 20 inches deep, and is known to have prior contamination.

Close monitoring of thermocouples in the east wall during heatup and cooldown, and frequent structural inspections, were required to preserve the pit and building from structural damage during the test.

The other walls of the pit which were exposed to the heat of the HGDS were not load-bearing, and were not subject to the same heatup/cooldown restrictions and monitoring as the east wall. The north pit wall is also load-bearing, but was isolated from the heat by the north primary containment wall.

A 4-foot-wide by 5-1/2-foot-high ventilation tunnel is located immediately behind the west pit wall, and was suspected to be contaminated due to its history and former function. The ventilation tunnel was physically connected to the unload booth locations, which were known to be contaminated. To retard off-gassing from these areas, the ventilation tunnel wall was insulated to reduce heat flow toward the ventilation tunnel and unload booth locations. The outside end of the ventilation tunnel was sealed from the outdoors by a wall constructed of metal studs and gypsum wall board.

Three tanks were left in the mustard pit during the field demonstration to test the effectiveness of the HGDS process on process equipment. Two 2,600-gallon steel tanks were previously used for mustard storage during demilitarization operations. These horizontal cylindrical tanks are located in the southern half of the pit, and are 19 feet long and 5 feet in diameter. A small condensate tank (horizontal cylindrical, 5 feet long and 3 feet in diameter) is located in the southwestern corner of the pit.

The building footing was not included in the target area for the field demonstration effort.

3.2.7 Electrical Design Considerations

The major design criteria for the electrical system included adequate capacity and fail-safe operation of the system in the event of power failure. The primary philosophy for the design of the power distribution system was that complete power failure was unacceptable. Design inputs incorporated into the electrical design of the HGDS electrical power distribution system included availability of utility line power, the calculated total electrical load, and project duration.

Electrical power was provided by two rented 500 KVA, 480 volt, 3 phase diesel generators, and from Public Service Co. of Colorado through an existing 750 KVA, 480 volt, 3 phase 3 wire ungrounded transformer. Redundant power supplies were required to meet the fail-safe requirement for electric power, which was met by the two trailer-mounted diesel generators.

One consequence of primary power failure was the loss of the ID fans and system negative pressure during startup of the backup generator. It was determined that a maximum time of one second could be allowed for transfer to backup power supply, to maintain negative pressure. This issue was addressed by making one diesel generator the primary power source, and making the utility transformer (line power) the secondary source. Startup and warm-up of the diesel generators took several minutes, which detracted from their effectiveness as the backup power source. An automatic transfer switch from primary to secondary power was located in the motor control center, with capability of transfer in less than one second. The automatic transfer switch continuously monitored the primary and secondary power sources, transferring to secondary power if primary is below minimum performance requirements. Transfer would only occur if the secondary source is within tolerances for operating performance. A manual transfer switch was furnished to allow only a single generator to be connected to the motor control center (MCC) at any one time.

A second generator was furnished in the system to act as a third power source and replace the first generator during routine maintenance. Routine service required that the unit be taken out-of-service for oil change after every 300 hours of operation. A diesel fuel tank was rented and sized for one week of operation by one generator. Diesel fuel for the generator was supplied by truck. The fuel tank was a 6,000 gallon concrete tank, constructed with a built-in secondary containment tank, to meet environmental regulations. Fuel storage and handling systems were installed according to applicable fire codes and safety guidelines. The location of the fuel storage tank is as shown in Figure 3.2.

The condition of the two diesel generators was monitored by local lube oil pressure gauges for each generator. Also, each generator was equipped with a low oil pressure shutdown feature, which tripped the generator in the event of low oil.

An Uninterruptable Power Supply (UPS) and distribution system was furnished to provide additional backup power to the control station and to condition (prevent surges to the power supply) power to the Programmable Logic Controller. Battery sizing of the UPS unit was based on one-half hour of backup operation of the control station.

The total electrical load was calculated during the design of the HGDS. It was anticipated that additional loads might be added during construction or operation of the system, and consequently a sufficient factor of safety was included for sizing of the generators and MCC to allow for load growth.

Outdoor site lighting was provided by two rented portable, self-powered trailers. Indoor lighting in Building 537 was from existing fixtures and lighting stands with plant power. Communication was provided by two-way radios and telephones in each trailer.

3.2.8 Construction Considerations

3.2.8.1 General

The primary parties participating in construction of the HGDS included the general construction contractor (Tennessee Valley Authority), the Resident Construction Manager and Engineer (Parsons Engineering Science, Inc.), and the environmental monitoring contractor (Battelle Columbus).

The construction contractor provided craft labor and technicians to construct the HGDS, and furnished construction consumables. The engineer provided detailed design drawings and specifications, and procured process equipment and materials. The environmental monitoring contractor furnished and installed environmental and process monitoring equipment. The Resident Construction Manager (RCM) provided management and oversight, and advised the contractor concerning design clarifications, intent of design documents, and project objectives and philosophy.

The Final Construction Drawings and Final Construction Specifications (September 1992) provided drawings, details, requirements, and procedures for construction of the HGDS. These were used by the construction contractor to build the project.

Construction of the HGDS was started in November 1992 and initial activities included foundation placement, material receiving, and pipe fabrication. A stop-work order was placed on January 13, 1993 at the request of Program Manager Rocky Mountain Arsenal (PMRMA), due to issues unrelated to the HGDS project. With permission of PMRMA, pipe fabrication continued inside Building 541 until March 1993, when all work was stopped. Full-scale construction resumed in August 1993 and was completed in December 1993.

A Construction Management Manual (December 1992) was prepared to present the construction schedule, construction management procedures and duties, documentation requirements, inspection procedures, and quality control/quality assurance requirements. The Construction Management Manual documented details of the responsibilities, activities, and functions of the project team during the construction. Quality control forms, quality assurance procedures, and a summary of the tasks were included in this document.

Quality control (QC) and quality assurance (QA) were two primary functions during construction. These functions were guided by the Quality Assurance Plan, Procurement and Construction Management Tasks (May 1993) and Amendments, the quality requirements presented in the specifications, and further detail in the Construction Management Manual.

During construction and operation, HGDS project personnel attended mandatory daily and weekly contractor meetings conducted by PMRMA. These meetings kept project field personnel informed of procedures, activities, and planned events at Rocky Mountain Arsenal.

The use of two buildings at the Arsenal were provided by PMRMA for construction support. Building 541 was furnished for materials receiving, indoor storage, and welding shop. Building 527 was provided for personnel shelter and break room.

3.2.8.2 Pre-Construction Phase

Several planning activities took place during the pre-construction phase included scoping, sequence planning, and scheduling.

An initial baseline schedule was developed which showed activities, activity durations, delivery milestones, and critical path for the project. The schedule was developed through the combined effort of the Resident Construction Manager and the Contractor. The project schedule was used to determine manpower requirements for labor and construction oversight to meet established milestones.

To facilitate the project and maintain schedule objectives, a site preparation activity was undertaken prior to construction. Several pre-construction activities were conducted and a site preparation guidance document was prepared to direct this work. The following tasks were undertaken:

- Process and electric equipment from secondary containment and primary containment areas was removed.
- Steel checkerplate above the pit was removed.
- Process and electrical equipment from process area and stack area was removed.
- Process pipe in the pit was decontaminated and removed.
- Penetrations in the pit walls were plugged.
- Trash and debris was removed from Building 537 and the HGDS process area.
- Combustible material was removed from the pit (including tanks supports, which were replaced by metal shims).

3.2.8.3 Process Construction Considerations

Main Burner and Fume Burner

The fume burner as purchased from the vendor did not conform to the geometric configuration or physical requirements of the specifications and drawings. The shop drawings which were required by the bid package were not received until after the equipment had been manufactured, shipped and received. Consequently, the engineer had no shop drawing to approve before manufacture and shipping, and the RCM had no drawings to inspect and receive delivery. Several field changes resulted from this circumstance, in order to fit the non-conforming purchase into the system.

The combustion air fans for the fume burner as received were integral to the unit, while the specifications called for free-standing fans. Instrumentation requirements dictated the use of stand alone fans. The combustion air fans were removed from the units and reinstalled in the desired configuration. The inlet boxes were repositioned on the fume burners to overcome interferences.

The gas trains as procured and delivered were larger than specified and shown on the design drawings. Their footprint exceeded the available space allotted in the area. It should be noted that the manufacturer had shipped the equipment before his shop drawings were received for review and approval. Location of the gas trains was revised to an area adjacent to the main process equipment.

The combustion air fans for the main burner and fume burners were undersized as delivered from the vendor. After much time, expense, and repair, these units were replaced by the manufacturer. Replacement of these fans required unplanned installation and calibration time. The combustion air pipe to the main burner was enlarged and reconfigured during the course of this work.

The intake filters for the combustion air fans were not adequately protected from the elements. Moisture collected on the filters and froze, reducing the flow intake of the blowers. Metal housings were field-fabricated to prevent precipitation from collecting on the filters.

The main gas regulator (purchased as low bid) did not meet process requirements, and was undersized, sluggish, and unresponsive to process changes. During testing, the unit was rebuilt, replaced with a larger unit, and finally replaced with another manufacturer's equipment. This caused several days delay in construction completion and considerable cost for maintenance repair and lost time. In the end, the low bid equipment was discarded and the higher bid equipment (as specified or equal) was purchased, at extra cost to the project.

Induced Draft Fans

The ID fans as received from the manufacturer were subject to excessive vibration and noise. The fan problems spanned 12 weeks during the pre-operational phase and throughout the operation of the system. The fans were directly responsible for a 7-week schedule delay of the project, and substantial additional work and expense for the construction contractor. A list of tests and repairs on the ID fans is as follows:

- Three vibration tests were conducted on the fans.
- Cracks from excessive vibration were repaired on the fan housings and the pipe-to-fan transition pieces.
- New pipe-to-fan transition pieces were fabricated of thicker wall construction after cracks reappeared on the pieces.
- The ID fan impellers were subjected to magnetic-particle inspection by a certified inspector to ensure mechanical integrity. No flaws or cracks were noted.
- The original base frames were replaced by sturdier base frames furnished and fabricated by the vendor and installed by the construction contractor.
- Additional gussets and braces were welded onto the frames and housings.
- Skillets were fabricated and installed over the fan air intakes in an effort to control flow turbulence.
- The metal expansion joints were replaced with flexible fabric expansion joints to dissipate vibrations.
- Instrument stands were fabricated and installed for the damper positioners due to performance problems resulting from excessive vibrations.

Test reports for factory testing of the ID fans were not submitted by the manufacturer, and consequently the operational status of the ID fans at the factory was not verified.

Radiator

The radiator as procured was much larger than specified and shown on the design drawings. Its footprint and envelope exceeded the available space allotted in the process area, and a major design revision was required. A complex and extensive piping revision and additional slab were required to accommodate the radiator as purchased.

During the initial inspection, the radiator as delivered was determined to have pressure leaks. Leaks were located and repaired during the construction phase.

The radiator was delivered without a supporting base. This was a source of contention between the engineer, who specified a fully functional and complete unit, and the manufacturer (Des Champs Laboratories). A steel frame base was required to support the radiator and promote air circulation. The base was fabricated and installed by the construction contractor to meet the manufacturer's specifications.

During operation, the radiator was observed to have fluid leakage problems. During early tests, suspected condensation from the radiator leaked onto the ground. Repair was not possible due to the configuration of the baffles. A record search did not indicate if a leak test had been conducted at the factory.

3.2.8.4 Mechanical Construction Considerations

Use of spiral-wound pipe as the primary piping material for process ductwork negatively impacted the quality and timeliness of piping fabrication. Upon material receipt, visual inspection of the spiral pipe (direct from the manufacturer) indicated excessive pin-holes and poor quality welds. It was necessary for the construction contractor to repair these problem areas before installing the pipe. The spiral pipe was often out-of-round, and spools were difficult to weld together. Since spools did not line up properly, a considerable amount of time and effort was needed to meet specifications for acceptable fit. Finally, the spiral pipe fittings did not match standard pipe dimensions, and in some cases did not match the drawings. This created problems at equipment interfaces.

The main natural gas supply pipeline was re-routed due to the poor structural condition of building structures. The driving factor in re-routing this line was unsafe working conditions.

3.2.8.5 Structural Construction Considerations

Primary Containment

Primary containment insulation was installed in the ventilation tunnel adjacent to the west wall of the pit. The insulation was required to contain heat in the pit area. The south end of the ventilation tunnel connected to a stack outside secondary containment. The ventilation tunnel was sealed with metal plate and high temperature caulking to preclude emissions.

The design called for bolted fastening of the gussets and structural members of the plenum frames. A double-fillet weld was substituted to provide the required strength, while saving fabrication time.

Secondary Containment

Cracks, penetrations, doors, and openings in the building walls used for secondary containment created breaches in containment, which were tedious and costly to seal. These openings were sealed during construction with grout, concrete block, and high temperature tape. During system testing, it was determined that the cinder block in the building walls were extremely porous, resulting in insufficient negative pressure in the secondary containment. Two coats of seal coating were applied on the building walls to seal containment, and lower the negative pressure to an acceptable level. After these efforts, negative pressure in secondary containment was still insufficient (less negative), but reasonable enough to proceed with the field demonstration.

The Hypalon membrane fabric used to seal the secondary containment wall was heavy and difficult to hang without wrinkles.

Pipe Supports

The system piping in the recirculation fan area could not be supported with pipe hangers as designed, due to the poor condition of the ceiling joists. Floor pipe supports were constructed to support the system piping.

A sliding support was designed for the 22" mixing chamber discharge line to the stack. An adjustable roller support was installed in place of the sliding support to provide vertical adjustment after the piping is in place.

A structural support was field-engineered and constructed to support the Rovalves at the mixing chamber. Upon delivery, the Rovalves were much larger and heavier than expected. Vendor drawings and specifications were not received prior to delivery.

The ambient air inlet assembly used for cooling air at the mixing chamber was intended to be self-supporting. No structural support was initially planned for this assembly, but stresses on the valves and piping were noted at installation. A pipe support was fabricated and welded in place to support the assembly.

3.2.8.6 Instrumentation Construction Considerations

One flow element was damaged during installation. The instruments were found to be very fragile, and the clearance between the instrument mount and the pipe diameter was insufficient to install the unit. Upon installation, the sensing element was crushed when forced into place. These particular instruments were extremely costly and time-consuming to have repaired by the factory.

Three thermocouples would not fit into the fume burner as delivered. The 3/4" pipe nipples were removed and replaced with 3/4" half-couplings, per manufacturer recommendations.

During loop checks of the field instrumentation, the contractor noted that communication radios were interfering with signals from the flow elements to the PLC. The solution (other than substantial insulation to the control wiring) was to avoid using the radios within 30 feet of the flow elements.

The air compressors for instrument air supply were not specified for outdoor service, and were installed without weather protection. During initial testing, the compressors had difficulty maintaining pressure and failed twice due to blown gaskets. Cold weather was suspected to be the source of the problem. Changing to a lighter oil and other adjustments proved ineffective. A heated shelter was constructed, which solved the problems and resulted in a reliable air supply.

3.2.8.7 Electrical Construction Considerations

Prior to the field demonstration, the utility transformer and line power had been energized but not loaded for many years. The transformer was load-bank tested to verify its suitability for use, and was found to be satisfactory.

The uninterruptible power supply failed its performance acceptance test on several occasions. As a critical safety system, these failures did not promote operator confidence. The problem with the UPS was the vendor-furnished used batteries. After much time and maintenance expense, the batteries were replaced with new batteries, which performed well in tests.

As presented in the design documents, power cable and control wiring were to be placed directly on the ground as a cost saving measure for a temporary installation. However, at the request of the construction/operation contractor, all conductors and wiring were placed in elevated cable trays. The complexity and sensitivity of the cable and information network required an organized site without electronic interferences or unnecessary tripping hazards. One exception was that multiconductor cable was placed directly on boards on the ground in accordance with National Electric Code Requirement for temporary installations.

3.2.8.8 Construction Safety Considerations

Personal protection standards and mandatory safety practices for all persons employed in the field demonstration of the HGDS were presented in the Final Safety Plan for the Field Demonstration of the Hot Gas Decontamination System" (September 1992). Safety issues were the primary drivers for the system design and construction. Under no circumstances were unsafe practices permitted during construction of the HGDS. The Final Safety Plan addresses environmental safety and health risk issues, hazard evaluation, physical hazards, heat and cold exposure, and emergency response plan. Personnel were trained on anticipated hazards, safety and personal protective equipment, safety practices, emergency procedures, and communications. Construction personnel were issued, trained, and fit tested with U.S. Army M-17 respirators.

No major safety incidents occurred during construction. Two minor safety incidents (personnel injuries) occurred during construction and were addressed as required by the Final Safety Plan. A site security program was undertaken to prevent the exposure of unauthorized people to site hazards and to prevent theft.

3.2.9 Procurement Considerations

A Final Equipment Procurement Strategy Guideline (September 1992) was prepared to guide the purchase of materials and equipment required to support the HGDS project. This procurement guideline specifically addresses the purchase of major equipment items and construction materials. It was developed to ensure that all schedules, costs, and coordination objectives are adequately addressed. Procurement procedures for the purchase of materials and equipment strictly adhered to professional purchasing practices consistent with the Uniform Commercial Code, the Federal Acquisition Regulations (FAR), and all applicable business laws and governmental regulations. Schedule and budgetary concerns were of primary importance in the procurement effort to ensure that all purchases were delivered to meet the startup schedule. The objective was to provide the maximum value per expenditure while maintaining quality assurance of all procurement and supply efforts.

Upon design initiation, it was identified that certain equipment would require long lead times for manufacture and delivery. An accelerated procurement schedule for this equipment was required to facilitate the HGDS startup. The particular equipment identified in this category included:

- Main Burner and Fume Burner Package.
- Stack.
- Induced Draft Fans and Recirculation Fans.
- Carbon Filter.
- Radiator.

Long-Lead Equipment Specifications and procurement documents were prepared which were separate and independent from the general construction specifications.

The design of process equipment centered upon the assumption that efficient and reasonably space-effective equipment would be procured. However, the government-required procurement system resulted in purchase from low bid vendors, who supplied equipment much larger than expected in practically every case. The process equipment consequently outgrew the original process area envelope during the procurement phase, resulting in major design revisions during the construction phase.

With the objective of reducing costs, an effort was made to rent equipment whenever available or practical. The use of rental equipment was limited to non-process equipment which were not exposed to hazardous process streams. The following equipment was rented for the HGDS:

- Control Trailer and Data Acquisition System Trailer.
- Power Generator Trailers (two).
- Uninterruptible Power Supply.
- Compressed Air Supply.
- Outdoor Lighting.
- Hand-Held Radios.

While the cost savings of equipment rental was a worthwhile objective, the equipment rented through the low-bid procurement process (particularly used equipment) was poor quality in some cases. The result was schedule delays, downtime, lost time for labor, and repair charges which were very costly in the final analysis. The Uninterruptible Power Supply, in particular, was furnished from the vendor as very used equipment and failed numerous times during testing, causing costly repairs and delays. The compressed air supply system for instrument air was another rented system which experienced considerable problems during startup due to cold temperatures. This unit was apparently not suited to outdoor service, and a heated enclosure was eventually built to house the unit. This was expensive and time-consuming.

Other equipment purchased as low bid caused much troubleshooting and repair, and long project delays. Examples are the induced draft fans and gas pressure regulator. Both units experienced major problems which caused project delays. The cost savings from low bid procurement was far outweighed by the cost of the repair, replacement, and time delay. In summary, the low bid procurement process created a significant added cost to the project due to purchase of poor quality equipment.

Schedules for delivery of some equipment and materials, including long-lead equipment, fabrication materials, and consumables, were not met. This created delays in construction and added cost due to labor forces standing down.

3.3 PROJECT ORGANIZATION AND RESPONSIBILITIES

3.3.1 Organizational Responsibilities

The organizations involved in the HGDS program were the USAEC, Program Manager Rocky Mountain Arsenal (PMRMA), Battelle Pacific Northwest Laboratories (PNL), Battelle Columbus Operations (BCO), Parsons Engineering Science, Inc. (Parsons ES), and Tennessee Valley Authority (TVA).

The contractual relationship of the above organizations and contractors was as follows. USAEC was the Program Manager and contracted directly with

PNL for engineering, procurement, operations, and project management services, and with TVA for installation and operations labor services, and to act as the Instrumentation, Control, and Monitoring (ICM) subcontractor. PNL was responsible for the technical management and conduct of the field demonstration. Parsons ES and BCO were subcontractors to PNL, and provided engineering and support services for the project. Parsons ES provided design and field engineering, procurement, and construction and operations management. BCO provided agent and emissions sampling and monitoring services. A summary of organizational responsibilities is presented in Table 3.10, and description is as follows.

Program Manager Rocky Mountain Arsenal

PMRMA manages the Rocky Mountain Arsenal and is the organization responsible for the cleanup of RMA. PMRMA was not directly contracted with any of the participating organizations for performance of this project. PMRMA provided Building 537 at RMA as the site for the HGDS demonstration. PMRMA reviewed and approved the plans and procedures of operation. PMRMA served as the public liaison and regulatory focal point for required environmental permits. Electric power, natural gas, and Standard Analytical Reference Materials (SARMS) for agent and analysis support for the agent samples were provided by PMRMA. Dilute SARMS solutions necessary for calibration of each automated chemical agent monitor and gas chromatograph were used. Two additional buildings (541 and 527) were furnished by RMA to support the project. Ultimate disposal of the hazardous materials generated was the responsibility of PMRMA.

U.S. Army Environmental Center

The USAEC was the developer of the HGDS technology, the funding agency, and the Program Manager for the U.S. Army. The USAEC coordinated activities between PMRMA, PNL, and TVA. The USAEC contracted directly with TVA for HGDS construction, installation, and operation support. USAEC contracted with PNL through the U.S. Department of Energy (DOE) for program management of the HGDS.

TABLE 3.10 ORGANIZATIONAL RESPONSIBILITIES

PROGRAM MANAGER ROCKY MOUNTAIN ARSENAL

Safety Support Coordination
Regulatory Permits and Approval/Public Relations
Receiving Area Security
SARMS for Calibration
Laboratory Space and Gas Chromatograph
Electric Line Power Supply
Natural Gas Supply
Water Supply
Ultimate Waste Disposal
Personnel Protective Equipment
Emergency Response Teams

BATTELLE PACIFIC NORTHWEST LABORATORIES

Project Management
Technical Support
QA/QC oversite

BATTELLE COLUMBUS OPERATIONS

Operation of the Data Acquisition System
Management of the Fume Burner Challenge
HD Surrogate for the Fume Burner Challenge
Operation of Stack Sampling
Stack Sampling Equipment
Operation of Process MINICAMS
Chemical and Surety Analysis
Technical Support

PARSONS ENGINEERING SCIENCE, INC.

Hot Gas System Design, Procurement, Construction and Operation Management
Utilities Connections and Distribution
Operations Plan
Site Decommissioning Plan
Personnel Support Facilities (Construction Trailer)
Health and Safety Management

TENNESSEE VALLEY AUTHORITY

Construction Personnel
Operators and Maintenance Personnel
Instrumentation, Control, and Monitoring Services
Operation of Two Ambient (work area) MINICAMS
Setup Decontamination Line
Decontamination and Removal of Agent-Contaminated Materials
Core Drilling of Pit Area and Installation of Thermocouples
Conduct Sampling Operations at End of Test Operation

Battelle Pacific Northwest Laboratories

Battelle PNL was the technical program manager responsible for managing the day-to-day activities, reviewing deliverables, and providing QA review and support to the program. Battelle Memorial Institute operates PNL for DOE in Richland, Washington.

Parsons Engineering Science, Inc.

Parsons ES was responsible for design engineering, field engineering, management of construction and installation of the HGDS, and management of the operation of the field demonstration. Also, the HGDS equipment was designed and procured by Parsons ES. Design for site modifications, utility hookups, and support facilities were the responsibility of Parsons ES. Planning and management of decommissioning and equipment disassembly after completion of the field demonstration was also the responsibility of Parsons ES.

During operation of the HGDS field demonstration, Parsons ES provided a Test Director, Test Engineers, and Lead Discipline Engineers and took responsibility for managing the operation of the field demonstration.

Parsons ES provided a 24-hour-per-day on-call Health and Safety Officer during field activities. A Quality Assurance Manager provided periodic reviews of procedures, records, and data to ensure that all project quality control and quality assurance procedures were being instituted.

Battelle Columbus Operations

Battelle Columbus provided sampling teams and non-agent chemical analysis support for the operation of the HGDS. The sampling team performed baseline, stack, ambient air, and post-operation sampling. BCO also conducted the sampling operations during the fume burner challenge. BCO chemists were qualified to work with chemical agent materials and supported the RMA laboratory in analyzing the samples. Sampling and monitoring of the site during and after HGDS operation was conducted by BCO with support from TVA. Battelle Columbus furnished and operated process air sampling equipment. BCO provided setup, maintenance, and operation of the Minicams, continuous emission monitors, EPA-method stack sampling equipment, and the Data Acquisition System (DAS) located in the control trailer. Data acquisition consisted of a system that automatically recorded operating conditions and provided data during the test.

Tennessee Valley Authority (TVA)

The Tennessee Valley Authority provided skilled craft labor and field instrument technicians to construct and install the HGDS. As the Instrumentation, Control, and Monitoring (ICM) System subcontractor, TVA was responsible for the entire ICM system installation including calibration, validation, programming, start-up, operational testing, and training of operating personnel. TVA was also the control program developer. In addition, TVA provided Operators, Control System Specialists, Health and Safety representatives, Minicam Operators, Instrument Technicians, and skilled craft labor for maintenance and trouble-shooting during operation of the HGDS. TVA operated two ambient air (work area) Minicams.

3.4 PROJECT SCHEDULE

The following lists milestone dates for key activities on the Field Demonstration of the Hot Gas Decontamination System.

Feasibility Studies for Decontamination Methods	February 1983
Pilot Test Operation (Dugway Proving Ground)	July 1987
Project Planning	September - December 1990
Stop Work/Funding Restriction (Operation Desert Storm)	January - August 1991
Preliminary Design	September 1991 - January 1992
Final Design	April 1992 - October 1992
Construction Start	November 1992
PMRMA Stop-Work Order/Partial Demobilization	January 1993
Stop Construction	March 1993
Re-Start Construction	August 1993
Construction Completion	December 1993
Pre-Operational Tests	January - February 1994
Field Demonstration Startup	March 3, 1994

Field Demonstration 24 HR Heat-Soak	March 17, 1994
Field Demonstration Completion	April 2, 1994
Pit Sampling Operations	April 14, 1994
Temporary Decommissioning	April 1994
Site Demobilization	May 16, 1994

3.5 REGULATORY APPROVAL

Public liaison and regulatory approval were the responsibility of PMRMA. The field demonstration of the HGDS was classified as a treatability study under CERCLA Remedial Investigation/Feasibility Study guidance for the RMA Installation Restoration Program. The U.S Environmental Protection Agency (EPA) and the Colorado Department of Health (CDH) were formally notified of the project scope and schedule on two occasions at regular monthly briefings at the Arsenal. A Draft Final Technical Plan (June 7, 1993) was presented to these agencies, which addressed project objectives, design and operation, sampling and analysis, risk assessment, health and safety, and schedule. Comments of the agencies were addressed and incorporated into the Final Technical Plan (November 24, 1993). A site tour for EPA and CDH personnel was conducted during construction of HGDS facilities to familiarize them with the project and answer questions. This disclosure approach satisfied the EPA and CDH representatives, who permitted operation of the field demonstration.

4.0 OPERATIONAL CONSIDERATIONS

4.1 GENERAL

Operation of the field demonstration of the HGDS was conducted from March 3, 1994 to April 1, 1994. The 24-hour heat soak which maintained pit concrete temperatures at 350 °F was conducted on March 17, 1994. The field demonstration successfully accomplished project objectives while meeting design criteria. During operations, the project team manned the project around the clock. Personnel on-duty during that time included one Control Systems Specialist and two plant operators from TVA, one Test Engineer from ES, and one Minicam operator from BCO. Routine maintenance and repair personnel were provided on the day shift by TVA, along with a Test Director from ES and a Data Acquisition Specialist from BCO. A five-person sampling team from Battelle Columbus conducted an air monitoring program to meet EPA method test requirements on several occasions.

Detailed information regarding the results of operation of the HGDS is presented in Section 6.0, Results and Discussion.

The Final Operations Plan (February 1994) was prepared to provide procedures, guidance and direction to operators for control decisions and safe operation of the HGDS. This plan was approved by USAEC, PMRMA, and other participating organizations. The plan addressed standard operating procedures for startup, normal operation and cooldown, systemization tests, emergency procedures and shutdown of the HGDS. Other topics addressed in the Final Operations Plan included a process description, project organization and schedule, instrumentation, control and monitoring descriptions, maintenance requirements, safety considerations, and pre-test and post-test activities.

The heart of the Final Operations Plan was the Standard Operating Procedures. Routine procedures for operation of the plant included:

- Pre-start Procedures
- Startup Procedures
- Heatup Procedures

- Steady State Operating Procedures
- Cooldown Procedures
- Shutdown Procedures
- Post-Shutdown Procedures
- Electric Generator Operation and Service
- Waste Management Procedures

Cautions were emphasized to alert operators of special conditions or procedures to protect equipment or safety. In addition, operating procedures for non-routine and failure conditions were presented for the following:

- Backup Mode Procedures
- Contain Mode Procedures
- Failure Condition Decision Guide

4.2 PRE-OPERATIONAL PHASE

Pre-Operational Testing

Pre-operational testing and component checkout took place during late December 1993 and January 1994. At that time, problems with vendor equipment caused the operations schedule to slip. The scheduled startup date was delayed from January 10 to March 3, 1994, while the contractor and manufacturer's representatives repaired and replaced equipment. The field demonstration was formally started on March 3, 1994.

Numerous inspections and tests were conducted to insure the HGDS was constructed, installed and operating according to performance and safety standards. Final pre-operational activities included minor repairs and adjustments to various pieces of equipment, and system checks and challenges prior to the full-scale systemization test and preoperational survey. Additional loop and calibration checks were performed on critical pieces of instrumentation prior to final start-up. System reviews and site walkthroughs were conducted by the engineer and contractor.

During component checkout and acceptance testing, each element of the HGDS system was tested and verified as functional. This final step in construction and installation of the HGDS verified that each element of the HGDS operated satisfactorily and safely in accordance with the specifications and drawings. Several types of acceptance testing were undertaken, including pneumatic tests, leak tests, electrical tests, mechanical functioning, and run-in tests. Detailed records of the test results were kept. Component checkout procedures (loop checks) and verification records for the Instrument and Control System were presented in the Final Operational Test Certification of the Instrumentation and Control System for the HGDS, by TVA.

Subsystem tests were conducted to insure that each subsystem, such as each ID fan, fume burner, and the main burner, was operated and verified as functional. After each component of the HGDS was tested and verified as functional, its subsystem was operated and tested to be within performance requirements. Individual components were grouped into subsystems according to the following organizational groupings:

- ID Fan No. 1, including stack and associated instruments
- ID Fan No. 2, including associated instruments
- Fume Burner No. 1, including gas train, combustion air fan, mixing chamber and associated instruments
- Fume Burner No. 2, including gas train, combustion air fan, and associated instruments
- Main Burner, including gas train, combustion air fan, and associated instruments
- Secondary Treatment Process, including radiator, carbon filter and associated instruments
- Electrical Systems, including generators, UPS and transfer switches
- Pit and secondary containment controls
- Recirculation fan and associated controls
- Instrument Air System and associated controls

The subsystem tests were followed by the systemization test, where the entire HGDS was operated with the mustard pit off-line to verify that the process system was functional. The "cold" bypass duct was used during this test to isolate the pit from the heat during the test. The test was conducted to insure that the entire system, including all subsystems and components were functioning according to performance requirements before the field demonstration on the mustard pit was initiated. The systemization test involved test of each of three system operational modes (Normal, Backup, and Contain Modes) and by simulating a number of failure scenarios. System response to simulated failure scenarios was evaluated to determine that all automatic safety responses programmed into the controls were operational. Simulated failure scenarios included forced occurrence of the following events;

- One fume burner failure
- Failure of both fume burners
- One ID fan failure
- Contain Mode Test (failure of both ID fans).
- Generator failure

A secondary containment in-leakage and pressure test was performed with the ID fans operating and no main burner heat into the system. This test confirmed that an adequate negative pressure in the secondary containment was reached.

Before the fume burner and mixing chamber were operated at full design temperature, the refractory brick in the fume burner and mixing chamber was cured by gradually heating the brick in controlled increments. This one-time controlled heatup was required to cure the brick and mortar to avoid cracking damage.

A fume burner challenge was conducted with the entire HGDS operating and the pit off-line using the cold bypass duct. The effectiveness of the fume burner to destroy volatile organic compounds was tested by injecting a non-toxic organic simulant into the system and measuring the destruction efficiency. A detailed description of the Fume Burner Challenge is presented in the Fume Burner Challenge Test Plan, Field Demonstration of the Hot Gas Decontamination System, Battelle Columbus, December 1993.

Government Acceptance

Prior to startup, a Government Operational Readiness Evaluation (ORE) was performed by USAEC and Program Manager Rocky Mountain Arsenal (PMRMA) representatives. The ORE examined construction, inspection, and test records, and planning documents to determine that the system was ready for operation. The HGDS Procurement Files and Construction Management Files were reviewed to confirm that acceptance criteria for the system have been met. Review and acceptance of project planning documents included review of the Final Operations Plan, Final Test Plan, Final Safety Plan, the Sampling and Analysis Plan and other project documents. An Operational Readiness Evaluation (ORE) Checklist was prepared, and signed for acceptance by representatives of the USAEC and PMRMA after a satisfactory review.

A Government Pre-Operational Survey was conducted by USAEC and PMRMA to survey the HGDS plant facilities, review personnel qualifications and training, and witness HGDS operations and safety procedures. This survey is performed to ensure that the project meets government standards, prior to initiation of the field demonstration. A "cold" demonstration run of the HGDS was performed with the mustard pit off-line and the bypass line in place. Several routine operations were demonstrated including system startup, heatup, Normal Mode operation, and cooldown. Several failure scenarios were demonstrated including a forced Backup Mode and Contain Mode, fume burner failures, ID fan failure, and power failure. Government personnel witnessed several contingency drills, including an agent emergency, personal injury emergency, and fire drill.

4.3 PROCESS OPERATIONAL CONSIDERATIONS

4.3.1 Process Control

The main objective of the pit heatup control was to heat all concrete areas of the pit walls and floors to the primary temperature criterion of

350 °F for a 24 hour period. Another objective of the pit heatup control was to ensure that the mustard pit received an even distribution of heat across the surface of the floors and walls. The maximum allowable temperature gradient across any cross-section of concrete walls and floor was 200 °F/ft. A maximum temperature of 750 °F on the inside surface of the pit concrete was another of the criteria monitored.

Temperature elements (thermocouples) located in the concrete of the mustard pit provided continuous heat input information to operators at the control station. The pit area had 117 thermocouples installed in 32 core holes in the floor and walls of the pit to monitor temperature and temperature gradients. Cores were equipped with two types of thermocouple arrangements; outside/outside and inside/center/outside(2)/soil. The thermocouple arrangements were designed to monitor inner and outer temperatures, and temperature gradient. A second thermocouple was provided for each outside thermocouple for redundancy.

Adjustments at the control station regulated the heat input and distribution to control the heatup and temperature gradients. Pit heating was controlled by modulating the main burner to control total heat input. The heat distribution to the north, center and south of the pit was regulated by throttling three butterfly valves on the downcomers from the inlet manifold.

Operations criteria required by the Final Operations Plan called for adherence to the temperature gradient limitation for the pit walls and floor. However, during operation it became apparent that the heat input to the west pit wall was limiting the overall heat input to the pit. This is due to the fact that the ventilation tunnel behind the west pit wall presented less thermal mass than the earth behind the east pit wall. Since the west pit wall was not structurally load-bearing, an operations decision was made to exceed the temperature gradient limitation in the west pit wall to facilitate timely pit heatup. Consequently, the east pit wall became the focus of the temperature gradient monitoring.

4.3.1.1 Modes of Operation

During operation of the HGDS, two of the three system operating modes were utilized. The Normal Mode was the primary mode of operation during the field demonstration. The Backup Mode was used on three occasions during operation. The Contain Mode was not used during operation and was only placed in service after the system was shutdown, at test completion.

The Backup Mode was used to treat the pit exhaust during startup, while ramping the fume burner up to temperature, and when the fume burner failed to meet minimum performance requirements.

The Backup Mode was used on three occasions during the field demonstration. At startup, use of the backup mode was necessary during ramp up of the fume burner to provide treatment of the exhaust gas. During operation, one brief excursion occurred where the fume burner temperature dropped below the allowable minimum. During cooldown, the Backup Mode was utilized after the fume burner was shutdown to provide additional treatment and cooldown of the pit after the heating operation was completed.

After the field demonstration was complete, during post-test core sampling, the Backup Mode was used to ventilate the pit for worker safety.

4.3.1.2 Phases of Operation

Three phases of operation took place during the field demonstration to meet project objectives: the mustard pit heatup, the heat soak, and cooldown phases.

The heatup of the mustard pit took approximately 14 days, which was reasonably close to the calculated heatup period of 11.5 days. The primary operation criteria for the heatup was a result of the requirement to protect the structural integrity of the building, and particularly the load-bearing east pit wall. A maximum temperature gradient allowed for the cross-section of the concrete was 200 °F per foot of concrete depth in the pit floor and walls.

Soil drying in the vicinity of the pit had a substantial effect on the heatup time. Plant operators observed venting of moist heated air in the vicinity of the east pit wall during the test. A consistent pattern of heatup of the pit was observed. After a uniform initial heatup, many outside thermocouples were noted to level off near 200 °F during heatup, sometimes for several days. Heat input at that point was used to meet the requirements of the heat of vaporization of moisture in the soil. After the soil in the vicinity of the thermocouple was dried, uniform heatup resumed.

The heat soak phase was the culmination of the test to meet the primary criteria of the Hot Gas technology, where all areas of the concrete are maintained at a minimum of 350 °F for 24 hours. The heat soak occurred on March 17, on the 15th day of operation. Heat input and operating conditions were maintained as in the heatup phase for the duration of the heat soak, which resulted in all thermocouples well above 350 °F at the end of the heat soak.

The cooldown phase to reduce the pit wall and floor temperatures to ambient temperatures began at the conclusion of the heat soak. The cooldown period lasted 14 days, until April 1 when the HGDS system was shut down. The allowable temperature gradient in the concrete of 200 °F per foot of concrete depth in the pit floor and walls was again the primary operations criterion in the cooldown phase. However, this was never approached in the pit during cooldown, and was not a consideration in the cooldown phase. In fact, the process system did not exhibit the ability to cool down the pit at an acceptable rate. Warmer than expected ambient air temperatures contributed to the slow cooldown.

The first operational step during the cooldown period was shutdown of the recirculation fan. Several field changes and procedure adjustments were required in the cooldown phase to accelerate pit cooling. However, these steps were limited by the flexibility of the process system and the operations procedures.

The main burner combustion air fan was operated at maximum output (with the burner off) to force more cooling air into the pit. Later, the main burner was physically removed to reduce pressure losses and increase air flow from the combustion air fan. The combustion air fan motor was eventually burned out during this service. The motor has since been replaced.

At one time, the recirculation fan was operated to determine if this would assist cooling. This step failed, and actually caused an increase in temperature during cooldown.

As the pit cooled over time, the concrete cooling slowed even further and appeared to assume an asymptotic curve. As the temperature of the concrete approached ambient air temperature, the delta temperature driving the cooling process dropped to unacceptable levels.

Finally, the HGDS process system was placed into the Backup Mode, to take advantage of the larger capacity of the carbon filter to process pit exhaust, which is primarily pit cooling air during cooldown.

The requirement in the Final Operations Plan for cooldown of the pit to ambient temperatures was determined to be unrealistic, particularly in view of the limitations for cooling of the process system. A field change in standard operating procedure for shutdown was made during the cooldown phase. The ambient temperature requirement for shutdown was deleted and replaced with a limit for safe personnel entry for burns to the skin (100 °F). The revised shutdown criterion of 100 °F for the pit concrete was reasonable and technically achievable.

As a result, the HGDS was shutdown after 3 days of operation in the Backup Mode, and inside pit thermocouples were below 100 °F.

4.4 PROCESS EQUIPMENT

4.4.1 General

The HGDS and process equipment were designed around operation during winter conditions. The maximum temperature for operation of the system was 70 °F. This limitation was approached and surpassed on numerous occasions during the field demonstration in March 1994, which was an unusually warm month.

4.4.2 Main Burner

During pre-operational testing of the main burner, the unit initially failed to meet performance standards. Initial startup and shakedown of the main burner was a difficult task, due to limitations of the equipment as furnished by the vendor. The specifications called for performance requirements which were not achieved by vendor products as received. The vendor-furnished combustion air fans were inadequately sized to meet the performance specification. The fans were eventually replaced, but a five week delay was experienced awaiting delivery of new combustion air fans. Troubleshooting the problem, removal and replacement of the fans, and the schedule delay contributed to extra construction cost.

4.4.3 Fume Burner

The fume burner experienced multiple difficulties during initial testing and startup, which resulted in time consuming and costly troubleshooting and repairs. This included problems with inadequately sized combustion air fans furnished by the vendor, and poorly performing gas pressure regulator. The vendor-furnished combustion air fans were also inadequately sized to meet the performance specification. The original and spare combustion air blowers for the main burner (as initially furnished by the vendor and found to be undersized) were used to replace the combustion air blowers for the fume burner. These fans operated satisfactorily for the fume burner, which was a fortunate coincidence.

The gas pressure regulator as purchased from Schlumberger did not respond to performance requirements of the system. The regulator was first dismantled and rebuilt, then replaced with a larger unit from the same vendor, and finally replaced with a different vendor's (Fisher) equipment, which was originally specified. The final replacement with Fisher equipment solved the problem and allowed the project to proceed.

Both fireyes on the fume burner were replaced prior to startup after one of the fireyes had failed.

The fume burner is a complex system with multiple factors affecting its operation. Several variables influenced the fume burner operating temperature, including process throughput, combustion air input, gas supply, and outside ambient air temperature. During operation, there was considerable thermal momentum experienced, and the fume burner was sluggish in response to system changes to meet operational objectives. Control of the temperature in the fume burner was a persistent problem. The difficulty in achieving and maintaining the required 2,000 °F led to the preliminary conclusion that the fume burner did not have sufficient capacity to heat the gas stream, and that the burner did not meet the design specifications. During post-test analysis of the data, discrepancies were noted between the measured natural gas flow and the flow rates shown from the pit to the fume burner. A series of calculations were performed to identify the source of the discrepancies. The conclusion drawn from the calculations is that the flow measuring device which indicated the flow rate into the fume burner from the pit was defective. It is believed to have reported consistently lower flow rates than actually experienced. These calculations are discussed in the results section of this report. The overall effect of this erroneous flowmeter reading was difficulty in achieving the design temperature in the fume burner, system instability because of additional cooling air required downstream, and a residence time less than the design requirement during part of the field demonstration.

The fume burner chamber was lined with refractory brick, which presented considerable thermal mass during heatup of the fume burner. Consequently, a substantial amount of time (approximately 15 hours) was required to bring the fume burner chamber from a cold start to operating temperature.

4.4.4 Mixing Chamber

The mixing chamber was a refractory lined, cylindrical horizontal steel chamber, of similar construction to the fume burner. The fume burner discharge at 2,000 °F was cooled in the mixing chamber by a combination of ventilation air from the secondary containment, and outside ambient air. The mixing chamber was operated in the range of 800 °F to 900 °F which was beyond its design temperature criteria of 575 °F. This is a result of the operational balance maintained between cooling air inlet flow in the mixing chamber and negative pressure in the system, which is increased when the ambient cooling air inlet valve is opened wider. The 800 to 900 °F temperature approaches the maximum limit for the carbon steel discharge system. The ID fans were protected from excess temperature by the long length of pipe in the discharge system from the mixing chamber to the fans, which provided significant cooling of the exhaust gas. This supplemented the mixing chamber and protected the ID fans from heat damage.

4.4.5 Radiator

The radiator was designed to reduce the temperature of the mixing chamber discharge from 575 °F to 120 °F, to protect the carbon filter media from excess temperature when the system was in the Backup Mode. The radiator was placed in service during initial pit heatup and fume burner ramp up, during a brief excursion when the fume burner dipped below temperature criteria, and during final cooldown. Each time the radiator was placed on-line, its design temperature criteria for operation was exceeded, due to the higher than expected temperatures from the mixing chamber. During testing and operation, the radiator met its performance objectives for cooling of process gas.

During operation in the Normal Mode (fume burner treatment train), process gas flow was observed through the backup treatment system, including the radiator. The radiator was off-line (by design) during the Normal Mode operation, and no process exhaust gas should pass through the radiator under this condition. It is presumed that one or two of the Fisher Posi-Seal Model A31A High Performance butterfly valves did not maintain a complete seal, causing leakage through the radiator. The failure of the Fisher Posi-Seal valves to correctly seat is more likely the result of maladjustment of the valves than a defect. In the future, pre-operational pressure testing and adjustment of the valves should correct this problem.

A considerable amount of water was observed coming from the bottom of the radiator during and immediately after operation with hot process exhaust in the Backup Mode. It is assumed that moisture in the process gas condensed in the radiator, and was the source of the leak. After the radiator was taken off-line and negative pressure became atmospheric, the condensate leakage out of the bottom of the radiator became more intense. It was not possible to examine the inner baffles of the radiator due to its configuration.

4.4.6 Carbon Filter

As the system was configured, ventilation air from the secondary containment was routed directly through the carbon filter prior to discharge. This process arrangement was designed for winter operation as the system was planned. The design inlet temperature to the carbon filter was set at 120 °F, due to temperature limitations of the carbon filter media. However, unusually warm weather experienced during March of 1994 (fourth warmest March in recorded history) contributed to excessive heat in the secondary containment. Also, heat emanating from the pit at the culmination of the field demonstration largely contributed to the high temperatures in secondary containment. As a consequence of these factors, the temperature of the ventilation air from the secondary containment to the carbon filter exceeded the maximum allowable of 130 °F and peaked at 140 °F while operating in the Normal Mode. A field change was implemented to remove insulation from ducting, and spray water on the duct from the secondary containment to the carbon filter. This uncontained water spray tended to be a minor nuisance on the ground in the process area.

In addition, several excursions to 140 °F were incurred in the Backup Mode as needed during operation, due to process requirements for the mixing chamber.

The granulated carbon media loses removal effectiveness above 130 °F, but is not damaged in this range. No damage or serious loss of efficiency should be incurred in the filter at 140 °F. No breakthrough of the carbon filter was detected at the midway monitoring point or damage to the media was found during the field demonstration.

4.4.7 Recirculation Fan

The recirculation fan was observed to be noisy at the culmination of the heatup period (after 13 days of operation). The fan was shut down at that time for the cooldown period. The fan was later operated at ambient temperatures with no evidence of vibration or noise.

4.4.8 <u>Induced Draft Fans</u>

A persistent problem during pre-test and operation of the HGDS was the lack of reliability of the ID fans. Both fans experienced excessive vibration and noise, and the north one had bearing overheating, while the south fan motor burned out. A substantial amount of time and maintenance labor was required to keep the fans in operating condition.

According to warranty conditions, the manufacturer was responsible for satisfactory fan operation during the one year warranty period. A factory repair representative was dispatched to the site on several occasions. His visits resulted in numerous repairs to the fans including impeller balancing several times, replacement of fan bases, shimming of fan bases, welded reinforcement of fan housing, base and inlet box. To expedite the project schedule, this effort was supported with engineering and maintenance labor by the construction manager and construction contractor. At the fan manufacturer's request, four high temperature flexible expansion joints ($1,000 each) were procured and installed on the two fan inlet and discharge ducts, to decrease stiffness at the end points of the fans. At completion of the field demonstration, it was noted that the fan bearings were still overheating, and showing excessive wear. The manufacturer has since replaced the bearings on both ID fans.

The noise levels of the fans appeared to exceed the design criteria of 85 dba level, one foot away as required by the specifications. This noise level was not verified by measurement with a sound meter.

During operation, it was noted that the industrial grade damper system on the ID fans would not securely close. Measured flow rates as high as 3,000 ACFM were observed with the dampers in the closed position, during ID fan operation.

4.4.9 Stack

No visible plume (steam, heat or particulates) was observed from the stack during operation. The temperature of the stack discharge was monitored in the range of 400° to 500 °F.

4.4.10 Mechanical

Cold Test Bypass Duct

Pre-operational changeover from the bypass line to the pit inlet manifold required manual removal of the spectacle blind inside secondary containment. This is a labor-intensive and time-consuming effort in secondary containment, and consequently the main burner and HGDS must be turned off during this task. This creates a dilemma during startup, since the pit ideally should be heated with the fume burner on line. Considering the 12 to 15 hour ramp-up time of the fume burner, the system must be operated through the carbon filter (Backup Mode) before switching to the fume burner treatment (Normal Mode).

An air intake nozzle was installed on the cold bypass loop during pre-operation testing. Since the pit was off-line during system testing, the air intake nozzle was used to simulate pit in-leakage.

4.4.11 Process Instrumentation

Prior to startup, process flow elements for the recirculation system and fume burner inlet failed, and were removed for factory repair and recalibration. The instruments appeared to have been overheated during the pre-operational testing of the main burner. The fume burner flow element was repaired at the factory and replaced in the system. The recirculation flow element was not repaired in time for startup and its location did not allow replacement during operation.

Inspections performed after the cool-down phase indicated that no significant damage had been incurred by system instrumentation, equipment, or structure.

The use of duplicate control station computers and control software proved to be invaluable during operation of the HGDS. This feature allowed two operators to monitor and control multiple systems data and functions.

In most cases, the instruments utilized on the HGDS performed very well, with some exceptions. The plastic positioners on the ID fan dampers as initially procured did not withstand the vibration of the fans. They were subsequently replaced with more durable positioners.

The flow meter that measured the flow into the fume burner from the pit was found to read consistently half or less than half of the actual value by extensive mass and energy calculations. This erroneous reading caused difficulty in achieving design flow rates, and caused the residence time to be less than two seconds most of the time.

The mass flow meters (Fluid Components Inc.) were found to be rather delicate and prone to damage during installation and operation. Also, these units were not capable of field calibration, and were capable of factory calibration only. Factory re-calibration typically took six weeks, due to service backlog, and was unreasonably expensive.

4.4.12 Electrical

The field demonstration of the HGDS was operated with diesel generator as the primary power source and utility line power as backup source. This backup power configuration was universally successful. The rental diesel generators proved to be highly reliable and trouble-free during round-the-clock operation.

The contractor requested the early delivery of one of the generators. Early delivery allowed the Contractor to install and check the main power system, train operating personnel, and test onsite equipment.

An instantaneous power outage (blink) was experienced during startup and testing of the HGDS while on utility line power. The power blink occurred at the Uninterruptible Power Supply, and did not present any obvious problems with the control system, until the system was tested for automatic system responses. At that time, the controls acted sluggish and unresponsive. The system was shutdown and re-booted to be returned to its normal operating condition. The timing of this blink was unfortunate in that it occurred several hours before the government witness Operational Readiness Evaluation, during which the system initially performed below expectations. In the future, the system should be re-booted (if possible) in the event of instantaneous power outage to the control station.

One scheduled outage of line power at Rocky Mountain Arsenal was successfully negotiated during operation of the HGDS by using one generator as primary power, and the second generator as secondary power.

Use of the UPS was never required or activated in its role as backup power for the control station. The opportunity never presented itself for use in any emergency scenario.

A transfer switch between the two diesel generators was required to prevent the possibility of simultaneous operation of the generators.

4.4.13 Agent and Emissions Monitoring

Monitoring of process gas streams was performed during the field demonstration to measure process performance and the type and amount of emissions generated. Three types of monitoring were carried out as follows:

- Continuous emission monitoring (oxygen, hydrocarbons, nitrogen oxides, sulfur dioxide, carbon monoxide, and carbon dioxide)
- Chemical agent monitoring (Minicams)
- Periodic stack sampling by EPA Methods.

The methods and equipment used for each of the monitoring types is described in the following sections.

4.4.13.1 Gaseous Emissions

The continuous emissions monitors measured gaseous emissions on a full-time basis. Because moisture and possible particulate matter may occur in the exhaust gas, continuous samples must be treated in heated filters and ice bath condensers to remove these materials. Solids and moisture in the samples contaminate the samples, produce interferences, and may damage the continuous emissions monitors.

Hydrocarbons (HC) generated from the process were sampled prior to the fume burner (where they were destroyed). The sample was taken from the burner inlet duct using a 3/8" stainless steel tube connected to a 1/2" heated flex sample line. The sample line was heated to approximately 250 °F to maintain moisture in the vapor state. The heated flex line was connected to a heated thimble filter to remove solids from the gas stream. The exit of the filter was directed to a stainless steel ice bath condenser to remove moisture from the gas stream. A vacuum pump located in the instrument laboratory pulled the clean-dry hydrocarbon sample through the sample line, into the appropriate flow monitoring devices, and then to the hydrocarbon analyzer for determination of HC content.

The ice bath condenser was used to reduce moisture to the gas analyzers. The moisture interferes with the operation of the non-dispersive infrared (NDIR) and oxygen analyzers. The gas is not bubbled through water so the impact on the monitoring of hydrocarbons (volatile), sulfur dioxide and NOx is minor based on past sampling activities on similar systems.

The levels of O_2, CO_2, CO, SO_2, and NO_x were sampled using a similar sampling system as provided for the HC analyses. The sampling point for these constituents was located in the transition piece between the fume burner and the mixing chamber, to provide higher concentrations before dilution with cooling air. Because of the relatively high exhaust temperatures at this location, a water cooled probe was used to quench the sample prior to the heated Teflon sampling line. Moisture and solids were removed with a heated filter and ice bath condenser prior to the respective continuous emissions monitors (CEMs).

The same emissions analyzers were used to monitor HC, O_2, CO_2, CO, SO_2 and NO_x from stack samples on an either/or basis. Flow selector valves provided the means to direct the sample flow from any of the three sampling locations to the analyzer. This meant that only one sampling location was monitored at a time. The majority of the time, the CEMs monitored the outlet of the fume burner while the hydrocarbon analyzer monitored the fume burner inlet. The outputs from the continuous emission monitoring, 0 to 10 VDC, were wired into the data acquisition system.

Calibration of the CEMS was performed daily, problems associated with the operation of the CEMS were corrected, and noted in the laboratory notebook.

4.4.13.2 Agent Monitoring

Minicams were used to provide a near real time (NRT) monitoring of process gas for the presence of mustard gas (HD). The Minicams were also necessary to provide a NRT HD ambient air monitoring capability to ensure environmental and worker safety. The Minicams monitoring of internal process streams provided an indication of the performance and effectiveness of the HGDS.

A redundant agent monitoring method was furnished in addition to the Minicams, to provide backup and confirmation of results. The method is a solid sorbent air sampling system known as the Depot Area Air Monitoring System (DAAMS tubes), currently utilized by the Army. The secondary method was to be employed in the event of a Minicams alarm, and would provide confirmation of HD vapor detection. Standard analytical chemistry protocol dictates that the secondary method has equal or greater sensitivity than the primary method. DAAMS tubes meet this requirement. They were selected as the backup system due to Army acceptance, and compatibility with RMA laboratory equipment to analyze the results.

The DAAMS tubes consist of a 60/80 series TENAX-TA mesh encased in a glass tube with openings at both ends. A sample is pulled through a duplicate pair of DAAMS tubes at a predetermined rate (typically one liter per minute) for a period of thirty minutes. The TENAX-TA media has a high binding affinity for the organic agent target analytes. Following the sampling period, the tubes are capped and transported to the laboratory. An analysis is performed on a standard analytical GC. The tubes are thermally treated to desorb the adsorbed analytes into the GC column.

The DAAMS tubes results are considered more accurate than the Minicams, since a standard laboratory analytical GC is equipped with a longer column capable of better separation and resolution. The DAAMS tubes are capable of both qualitative and quantitative analysis for chemical agent (HD) contamination at much lower concentrations than the Minicams.

During the field demonstration, the DAAMS tubes were planned for use only in the event of a true Minicam alarm.

4.4.13.3 Stack Sampling

In addition to continuous monitoring and agent monitoring, the stack was sampled and monitored to detect other emissions from the field demonstration. Stack sampling included performance testing for emissions releases by Environmental Protection Agency (EPA) Method 5, using an impinger sampling train for particulate material and metals (EPA Methods 5 and 29). Another Method 5 sampling system was modified to include an XAD-2 polymer adsorbent, to allow determination of organic breakthrough species (HD and breakdown products). In addition, Summa canisters were used to take a 30 minute composite sample for organic analysis. The Modified Method 5 (MM5) train was used to perform EPA Method 23. A third sampling system included a determination of HCl emissions by California Method 421.

A stack sampling port was located near the top of the stack, and a crow's nest and supporting scaffolding was provided for sampling personnel. For the field demonstration, a total of nine particulate and metals tests, ten organics tests, and nine acid gas sampling trains were conducted at the stack. Method 5 tests used procedures specified in 40 CFR Part 60, except that a high purity quartz fiber filter and a dilute HNO_3 rinse solution were used. The stack sampling tests were conducted four times during the field demonstration, including:

- During pre-operational tests before the pit was on-line (baseline)
- During heat up of the pit
- During the heat soak after thermocouple temperatures reached 350 °F

- During cool down of the pit when the main burner was off

For sampling, two 4-inch threaded and capped sampling ports were installed on the stack in accordance with the specifications in EPA Method 1A. Sample preparations and recovery were conducted in a mobile monitoring facility using protocols established for the EPA procedures.

Samples were recorded immediately after each sampling period and analysis were made for the following:

- Total particulate emission (Method 5)
- Metal emissions (Method 29)
- Volatile organics from XAD-2 sorbent cartridge (Method 23)
- HCl from collected condensate and acidic impinger solution (Method 421)
- Summa canister (Method 18)

One blank MM5 train for organic background determinations, and a blank of each reagent and media material (filter) were prepared. Each test set also included an integrated Summa canister sample of effluent gas.

4.4.13.4 Gas Sampling Methods

Methods used for collection of exhaust gas samples are presented in Table 4.1. Standard methods are discussed in the following paragraphs, with any modifications detailed. The flue gas sampling methods described below were utilized for characterization of the target analytes.

USEPA Method 29 (Draft June, 1992) - Multiple Metals

Method 29 (Draft 6/92) is designed to determine emissions of 13 metals from stationary sources. In Method 29, flue gas is withdrawn isokinetically from the source. Particulate emissions are collected in the probe and on a heated filter, and gaseous emissions are collected in a series of chilled impingers. Two impingers contain a solution of 5% nitric acid and 10% hydrogen peroxide, and two impingers contain a solution of acidic potassium permanganate. The following metals of interest were analyzed for the HGDS:

- Chromium (Cr)
- Arsenic (As)
- Mercury (Hg)
- Cadmium (Cd)
- Nickel (Ni)

TABLE 4.1 SAMPLING METHODS

Sample Description	Location	EPA Method
Metal	Stack	29
Semivolatile Organics	Stack	23
Volatile Organics	Stack	18
HCl/Particulate	Stack	CA 421

California Method 421 - Acid-Gases Hydrogen Chloride

Method 421 is designed to determine hydrogen halides in the absence of other chloride-containing volatile species. It is suitable for combustion sources where the primary source of chloride is the dissociation of chlorinated organic compounds. Method 421 was used as published in Stationary Source Test Methods, Volume III, State of California Air Resources Board, December 13, 1981.

A sample of gas is withdrawn isokinetically from the source. Particulate emissions are collected in the probe and on a heated filter housing, and gaseous emissions are collected in a series of chilled impingers. A solution of dilute sodium bicarbonate is contained in one impinger, and dilute sodium carbonate in another.

USEPA Method 23 - Semivolatile Organic Compounds

Method 23 is designed to determine semivolatile (boiling points greater than 100 °C) Principal Organic Hazardous Constituents (POHCs) in the flue gas of stationary sources. The method, published in 40 CFR 60, Appendix A, dated

December 31, 1992, was used to collect samples to screen for the following semivolatile organic species:

- Mustard breakdown products
- Polynuclear Aromatic Hydrocarbons (PAH)

USEPA Method 18 - Gaseous Organic Compounds

Method 18 is designed to determine volatile organic compounds from stationary sources. The Method, published in 40 CFR 60 Appendix A dated February 13, 1991, places an empty 30 liter Tevlar bag in a sealed rigid container. A vacuum pump evacuates the container and draws a grab sample into the Tevlar bag. For this project, the method was modified to use an evacuated 6L Summa Can to take volatile organic samples.

4.4.13.5 Minicams Dilution Boxes

Dilution boxes were used as gas conditioners for the Minicams to lower the gas temperature and moisture concentration of high temperature gas streams from combustion processes in the HGDS. The three units on the HGDS were used at the following locations: on the inlet and outlet to the fume burner, and at the stack. The dilution boxes bleed in a set amount of dry air and mixed it with the gas samples from the process stream. The dry air cools and lowers the moisture concentration of the process gas stream. The dilution box flow conditions were established and checked at the start of the test using a gas rotameter. During the test, injections to challenge the Minicams to confirm their calibration were made at the dilution box. The dilution box injection port supplies the challenge material into the line to the Minicams after the dry air has already been mixed.

The Minicams were working to specifications and responding to the challenges within the acceptable levels. The Minicams were indicating no response to materials entering and exiting the fume burner. One night when the dry air cylinder for the inlet and outlet dilution boxes for the fume burner became empty, the Minicams started to show response to daughter products of mustard on the strip chart recorder. This indicated that there was a problem with the dilution box. After checking, it was found that the dry air flow had increased and prevented a sample from being taken from the process streams. The dilution box at the stack was checked and found to be working correctly. All three dilution boxes were removed from service and the Minicams then sampled the hot process gas streams directly. The Tenax preconcentrator tubes on the Minicams monitoring the fume burner inlet had to be changed out frequently but the Minicams worked and provided real-time readings of the hot process gas streams.

As a check that no agent was released, DAAMS tubes were taken, analyzed, and confirmed that no mustard was present in the process gas streams during the time that there was a problem with the dilution boxes.

4.4.13.6 Concrete Core Samples

The concrete core samples taken from the pit after the test were ground and extracted with solvent. The solvent was then injected into either a GC or GC-MS for analysis. This provided quantification of mustard, dithiane, and oxathiane. Other sulfur by-products may not be picked up by this method of analysis.

4.4.13.7 Placement of Sampling Lines

The gas sampling lines used at the test site for continuous emissions monitoring were polypropylene and were placed in a protective PVC piping located under the duct going to the ID fans. The high temperature of the ducting was sufficient to degrade the PVC and melt one of the gas sampling lines inside the PVC to where it collapsed. The replacement of the line was hampered by the high temperature of the ducting.

4.4.13.8 Thermocouples

The type K, 1/16 inch 304 stainless steel sheath, ungrounded junctions, thermocouples exceeded specifications for monitoring the temperature profiles in the concrete. The thermocouples had a Marlox high temperature transition junction connecting the extension wire to the thermocouple element. During heat up, five of the 117 thermocouples in the pit gave noisy signals, as the temperature readings varied considerably. Later in the test, the five behaved and all 117 thermocouples provided good readings. These thermocouples used for monitoring the concrete temperature profiles during heat-up and cool-down are recommended for future projects.

4.4.13.9 Data Acquisition System

The Data Acquisition System (DAS) operated continuously during the operational test of the HGDS. During the field demonstration, there were times where short durations of data were lost. This occurred when data exchange via Windows Dynamic Data Exchange (DDE) had problems. This usually occurred when too many operations were being performed on the DAS. Other than a few problems with the DDE, the DAS performed to expectations.

The DAS allowed the operator to select the data update rate (15 seconds to 1 minute) and the rate at which the data was archived (1,5, or 10 minutes). During the field demonstration, data was archived every 5 minutes. The DAS also allowed the operator to take a one hour snap-shot of the last hour of data in a separate data file. The snap-shot allowed an operator to save high frequency data for certain events so that if events changed rapidly, the data could be stored for later analysis. During the field demonstration the sampling rate was usually set at every 30 seconds.

The DAS performed reasonably well, except for several instances were the system stopped archiving data. The reason appeared to be a timing conflict with the software and the data highway. Little data was lost during DAS stoppages.

4.5 STRUCTURAL CONSIDERATIONS

During the field demonstration, a large crack appeared on the loading dock floor on the northeast corner of the building outside of the containment area. It was determined that the cracking was the result of a localized consolidation of the supporting soils under the loading dock floor. As the heating process progressed, the water in the surrounding soils began to evaporate. The soil consolidated and created the cracking in the slab. Also, numerous hairline cracks were observed in the structural columns during operation of the HGDS. These cracks were due to differential expansion of the columns, and were anticipated. Substantial cracking between the cinder block walls of the building and structural columns was noted during HGDS operation. This was theorized to be due to heat drying and shrinkage of the cinder block. In all, damage to the building was superficial from a structural standpoint, and did not affect the structural components of the building.

Although the integrity of the building was never in question due to the superficial cracking, the cracks did require caulking to maintain negative pressure in secondary containment.

Due to operational requirements, the west pit wall received a higher temperature gradient than anticipated prior to the test. Since the pit walls and floor of the west pit are now covered by the plenum, they have not been inspected to determine the structural effects of the excess temperature gradient to the pit wall. After decommissioning, a structural inspection of the west pit wall (as well as the entire pit) will result in valuable information for future projects.

4.5.1 Secondary Containment

During operation, personnel entry was prohibited into the secondary containment for safety reasons.

During the field demonstration, the air inlet louver to secondary containment was sealed closed, when it was determined to be redundant due to in-leakage through the building walls. Conversely during the cooldown period, the air inlet louver was propped opened to facilitate increased cooling.

4.6 OPERATIONAL SAFETY CONSIDERATIONS

The Final Safety Plan for the Field Demonstration of the Hot Gas Decontamination System (September 1992) set personal protection standards and mandatory safety practices for operations personnel. In addition, the Final Operations Plan (February 1994) contained site-specific information and provides responses for contingencies that may arise during HGDS field activities. The Final Operations Plan presented the site safety layout for the HGDS operation, including exclusion zone, contamination zone, hot line location, safety zone, and safety equipment location.

Safe operation was the primary directive for startup and operation of the HGDS system. Protection of plant operators and the general public was the over-riding concern during all phases of the HGDS operation. All standard operating procedures were developed with safety considerations as the prime motivator. Safety issues were the primary drivers for the system design, startup and operation logic, and control decisions. During startup and operation of the HGDS, control decisions were made such that no health and safety criteria were compromised.

Health and safety concerns generally determine the number of operators required on the job site during system operation. Two plant operators are the minimum number to handle the general duties during normal operations. However, four operators were required at the site at all times during operation to handle emergencies and follow contingency plans.

Operations personnel were issued, trained, and fit-tested with U.S. Army M-17 respirators by an RMA representative. After start up, HGDS personnel carried the M-17 on their person while onsite.

Site-specific safety and health briefings were conducted by safety representatives for personnel who engaged in the HGDS operation. This training specifically addressed procedures, monitoring, and safety equipment, site layout, potential hazards, and emergency response.

Daily safety inspections were conducted during operation to ensure that a safe work environment was maintained at the site. These inspections were performed to detect, identify, and control potential hazards before accidents occur.

Adequate communication facilities were a critical part of the safety program. A public address system and hand-held 2-way radios were used by the operators to alert personnel onsite of emergency situations. Telephones were located in the control trailer and construction manager's trailer to call the RMA Fire Protection and Prevention Branch for emergency assistance.

5.0 QUALITY ASSURANCE/QUALITY CONTROL CONSIDERATIONS

5.1 GENERAL

Quality control (QC) and quality assurance (QA) were an integral part of the project through all phases of development. A quality assurance plan was effective during each phase of the work, and contained requirements for design control, change control, procedures, document control, QA/QC records, audits and surveillances, control of purchased items and non-conformances, and corrective actions. QA/QC requirements and procedures were established for the preliminary design, detailed design, procurement, construction, and operations tasks. Quality assurance for the design, procurement, construction, and operations of the process equipment for the HGDS was the responsibility of Parsons Engineering Science, Inc. Quality assurance for the design, procurement, installation, and operation of emissions and agent monitoring equipment for the HGDS was the responsibility of Battelle Columbus Operations.

A Quality Assurance Manager (QAM) was assigned to implement the QA requirements during performance of the project. This authority was exercised by:

- Representing project management in quality-related matters
- Interfacing with project personnel to ensure interchange on quality requirements
- Providing assistance and guidance on matters pertaining to quality
- Evaluating the effectiveness of project/operational activities through performance of surveillances and reviews, and by offering recommendations for improvements
- Verifying conformance to requirements and completion of corrective actions
- Reporting the status of QA activities to project management

The QAM had the authority and independence to identify quality-related problems, evaluate solutions, identify corrective actions, and verify implementation of corrective actions.

5.2 DESIGN PHASE

Quality assurance requirements for the preliminary design were presented in the Quality Assurance Plan, Phase I, Tasks 1, 2, and 5 (November 1990). This document focused on procedures and requirements for design verification reviews, design control and changes, intradiscipline and interdiscipline reviews, and recordkeeping.

The Quality Assurance Plan, Equipment Design Task (October 1991), addressed QA considerations for the detailed design. Design activities were controlled through the review process, including intradiscipline checks and interdiscipline reviews. Drawings, specifications, and final design calculations were verified, and documentary evidence was maintained. Design documents were released for final use after verification was made that comments were resolved and incorporated. The record of the checking and review process included signatures and dates on routing records, approval records, discipline check and interdiscipline review prints, and review meeting minutes.

Project-specific procedures were developed for implementing the design task QA Plan for the following areas:

- Design Control
- Design Development
- Intradiscipline Review
- Interdiscipline Review
- Peer and Technical Review
- Client Review
- Design Change Control
- Control of Purchased Items and Services

- Non-Conformance Control
- Control of Processes
- Inspection
- Test Control
- Recordkeeping

Two surveillances were conducted during the design phase. Minor deficiencies were noted and corrective actions were implemented.

5.3 PROCUREMENT AND CONSTRUCTION

The Final Quality Assurance Plan, Procurement and Construction Management Tasks, detailed QA requirements for the procurement and construction phases of the project. This document ensured that the materials and equipment purchased and construction work performed met the quality standards of the specifications and drawings.

Quality assurance requirements for indoctrination and training, reporting, tracking, auditing, and management assessment were stated in the QA Plan. In addition, detailed QA requirements are specified for the following elements applicable to the procurement and construction tasks:

- Project Organization
- QA Program
- Design and Specification Change Control
- Document Control
- QA and Project Record Control
- Procurement Document Control
- Control of Processes
- Control of Purchased Items and Services

- Control of Measuring and Test Equipment
- Identification and Control of Items
- Inspections
- Test Control
- Inspection, Test, and Operating Status
- Control of Non-Conforming Items
- Corrective Action
- Surveillances
- Instructions, Procedures, and Drawings

Project-specific procedures for each of these categories were developed and presented in the Construction Management Manual (December 1992). All technical personnel and task managers were required to review the QA Plan and procedures, and sign an acceptance form, verifying their concurrence with the conduct of the work. Quality standards for procurement, materials acceptance, and construction were presented in the General Construction Specifications and Drawings, and Long-Lead Equipment Specifications.

During construction, the contractor was responsible for the quality of construction, while the Resident Construction Manager (RCM) had the responsibility to effectively implement the QA program. The RCM performed the following activities for this purpose:

- Monitored compliance of the construction contractor with regard to quality requirements of the design documents
- Monitored compliance of the construction contractor and vendors with applicable federal, state, and local codes, standards and regulations, and commercial practices and standards

- Functioned as the client's onsite representative in matters pertaining to specification or design change control and the acceptance of services, material, and equipment

- Interfaced with the QAM on matters pertaining to quality

- Ensured that quality-related issues were identified and reported

- Ensured that approved and documented corrective actions were implemented by the construction contractor or vendors

- Maintained appropriate QA records and documentation in accordance with task record control requirements

A Quality Assurance Surveillance of the HGDS was conducted by a Battelle PNL representative on the dates of January 10 to 12, 1994. A Source Verification Report (SVR) was completed by Battelle PNL and documented the activities and deficiencies found or observed during the performance of the surveillance.

The SVR noted three Findings and two Observations. The SVR was received on January 25, 1994. A written response was required for Findings #1 and #2 within 30 days from the receipt of the SVR, while a written response was required for Finding #3 within 5 days from the receipt of the SVR. Observations #1 and #2 only required a written commentary to be submitted within 30 days from the receipt of the SVR. The focus of the responses included: 1) how to resolve the noted deficiency, 2) how to prevent further occurrence of the deficiency, and 3) a date that listed when the changes would be implemented. Response to the SVR was accomplished in a timely manner and with all responses and commentary accepted by Battelle PNL.

A summary of the Findings, Observations, and Responses is as follows:

Finding #1: Adequate indoctrination, training and evaluation of personnel assigned to the HGDS project as required by the Final Quality Assurance Plan (QAP). Section 3.3 of the Quality Assurance Plan for the Field Demonstration of the Hot Gas Decontamination System - Procurement and Construction Tasks provides for the indoctrination and training of personnel performing activities affecting quality. This section requires that task participants including the construction management be "qualified by educational training, technical knowledge, and/or experience to perform assigned functions." Objective evidence that evaluation, training and indoctrination had occurred was not provided. It was acknowledged that the appropriate documentation (QA Acceptance form) had not been prepared.

Response to Finding #1: The deficiency was in record keeping for the Construction Management Task only. Indoctrination, training and evaluation of personnel were immediately performed according to the project quality assurance (QA) requirements for the Construction Management Task. During the Design Task, indoctrination, training and evaluation of personnel were performed with the appropriate record keeping to meet QA requirements. QA Acceptance Forms were distributed to all appropriate personnel, signed, and filed in the project files. During the field demonstration phase, all Test Engineers and Lead Discipline Engineers were required to review the Operations Addendum to the QA Plan and sign a new QA Acceptance Form.

Finding #2: Not all items and materials designated in Section 9.2 of the Final Quality Assurance Plan were identified and controlled from receipt to installation. Section 9.2 designates materials and items to be identified and controlled on the HGDS project. The controls were required to be implemented in accordance with procedure ES-PQAP-08-DE-01. It was observed during the walk down that items on the list were not being identified and controlled. It was acknowledged that the list of controlled materials was inaccurate and needed revision.

Response to Finding #2: The list of items to be controlled, as listed in Section 9.2 of the HGDS Procurement and Construction Management Task QA Plan, was acknowledged to be inaccurate and was revised to require materials control on a revised list of items. The new list of items was identified, controlled, and traceable.

Finding #3: The qualifications for personnel performing special processes and inspection were inadequate. Procedure ES-PQAP-10-DE-01 requires that inspections be performed by qualified personnel. The Final

Construction Specifications for the HGDS (Section 15052-6, para. 1.7.3.1) requires the individuals performing visual weld inspection be a Certified Welding Inspector in accordance with AWS QC-1. No evidence could be provided that the inspector (Richard Moore) had such a qualification. The HGDS Final Construction Specification required that the code and procedure under which each welder is qualified for shall be stated on the certification of the welders qualification tests. It was noted that the welder qualification documents for Thomas Floyd Steel (dated 11/6/92), James Harris (dated 11/6/92), Mike Hardeman (dated 11/12/92) and Curtis Ricks (dated 11/12/92) did not reference the welding procedure that the welder had qualified for.

Response to Finding #3: All visual weld inspections were certified by Mr. Leaster Stigall who is a Certified Welding Inspector in accordance with AWS QC-1. A certificate was submitted to Battelle PNL. Furthermore, another independent visual welding inspection in accordance with AWS QC-1 was performed by MQS Inspection, Inc. on February 17, 1994. All visible field welds were reinspected and repaired, as necessary, and reinspected. Inspection reports and a Certified Welding Inspector certificate were filed for the record. The code and procedure under which each welder was qualified was reissued by Intermountain Testing Company (ITC), which conducted the welder qualification tests. All necessary qualification documents were reissued.

Observation #1: It was noted that the separate, monthly QA reports as required by Section 3.4 of the QA Plan have not been prepared.

Response to Observation #1: Each HGDS Monthly Status Report, submitted to Battelle PNL addressed QA status reports. The Project Quality Assurance Officer contributed to the report as required.

Observation #2: It was observed the Request for Information Reports (RFI) were signed by the Resident Construction Manager whereas ES-PQAP-03-DE-01 requires the review and approval of the Project Director or the Lead Mechanical Engineer for mechanical/design revisions. For structural design revisions, review and approval by the Project Director or the Lead Structural Engineer is required.

Response to Observation #2: The implementing procedure utilized for design and specification control (ES-PQAP-03-DE-01) required an unnecessary level of control that exceeded ES-PQAP requirements and was revised (Revision 3/2/94) to accurately document the process that was utilized for the HGDS procurement and construction management activities.

5.4 PROCESS OPERATIONS

Quality assurance for pre-operational testing and system operation was governed by the Final Quality Assurance Plan, Procurement and Construction Management Tasks as amended with an Addendum for the operations phase. Quality control requirements for the pre-operational systems tests and operations were presented in the Final Operations Plan (February 1994). During testing and operations, the test engineer on duty performed QA monitoring of the field demonstration.

Prior to full-scale operation of the HGDS and heatup of the pit, extensive pre-operational testing of the system and components was required. Quality control activities during the pre-operations phase consisted of equipment and system inspections, tests, evaluations, and surveys, as required in the specifications and drawings. Appropriate certification reports and documentation were completed for each test or inspection activity. Pre-test activities which occurred prior to plant operation included the following:

- Component checkout and acceptance testing: each element of the HGDS was tested and verified as functional
- Subsystem tests: each subsystem was operated and verified as functional
- Systemization Test: the entire HGDS was operated with the Mustard Thaw Pit off-line to verify the functionality of the system
- Fume Burner Challenge: a non-hazardous organic compound was injected into the system to measure system destruction efficiency; the system was operated in the same mode as the Systemization Test

- Final Operational Test Certification of the Instrument and Control System: Instrument technicians tested and verified proper design, installation, and operation of instruments and controls over a range of operating conditions

- Government Operational Readiness Evaluation (ORE): USAEC and PMRMA representatives examined construction and installation records to determine system readiness

- Government Pre-Operational Survey: USAEC and PMRMA representatives surveyed the HGDS plant facility, operator and test engineer personnel qualifications and training, and operations and safety procedures to ensure that the project met government standards

Quality assurance elements which received special emphasis during the pre-operational testing and operations phase included:

- Design and Specification Change Control
- QA and Project Record Control
- Control of Purchased Items and Services
- Control of Measuring and Test Equipment
- Identification and Control of Items
- Inspections
- Test Control
- Inspection, Test, and Operating Status
- Nonconformance Control
- Corrective Action
- Surveillances

Project-specific procedures for each of these elements were prepared and followed.

5.5 SAMPLING AND ANALYTICAL

5.5.1 General

Quality control and quality assurance were applied to all activities associated with collection of test data, including compilation and review of analytical, emission, and sampling data. Regarding sampling, analysis, and data, QA/QC was applied to the thermocouples used to monitor the concrete temperatures, the continuous emissions monitors (CEMs), stack sampling, agent monitors (Minicams), and chemical analysis of samples. A Final Sampling and Analysis Plan (February 1994) was prepared and approved by USAEC and PMRMA for conduct of data gathering activities. This document stated data quality objectives, sampling methods and custody procedures, calibration procedures and frequency, analytical methods, data reduction, validation and reporting requirements, quality control procedures, precision and accuracy requirements, and performance of audits.

An Onsite Precision and Accuracy (P&A) Test Plan and Quality Assurance Plan for the Minicams were prepared and approved by USAEC and PMRMA. The P&A Test established certification requirements for Minicams, and requirements for operators to complete an operator proficiency demonstration. The QA Plan for the Minicams addressed such issues as reference materials, certification, operator training, calibration and challenge, sample collection and analysis, documentation, and quality control requirements.

Specific details and results regarding performance of the QA/QC program for the sampling and analytical data are in the following sections of this report.

5.5.2 Field Sampling

QA/QC of sampling systems included following the EPA Sampling Method operating procedures, which establish the calibration frequency requirements and acceptance criteria. Standard procedures required calibration of all equipment immediately prior to and after field sampling. These calibrations were done using established protocols, including EPA-approved, ASTM, and/or National Institute of Standard and Testing (NIST)-traceable reference equipment where applicable. Calibration frequencies, limits, and results are shown in Table 5.1.

Required calibrations specified in sampling procedures were performed on sample train equipment prior to commencement of sampling activities. If at any time during testing, the operator had reason to believe a piece of equipment may no longer be in calibration, a recalibration was performed to verify accuracy.

Equipment which required calibration included meter boxes, thermocouples, nozzles, and pitot tubes. Referenced calibration procedures were followed when available, and the results were properly documented and retained in a calibration log book. The log book was available onsite for review and is now part of the project files. If a reference calibration technique for a particular piece of apparatus was not available, then a state-of-the-art technique was used. A discussion of the techniques used to calibrate the sampling equipment is presented below.

Sampling Nozzle Calibration

Calculation of the isokinetic sampling rate requires that the cross-sectional area of the sampling nozzle be accurately and precisely known. All nozzles used for Methods 29/421 sampling were thoroughly cleaned, visually inspected, measured, and calibrated.

Temperature Measuring Device Calibration

Accurate temperature measurements are required during source sampling. Bimetallic stem thermometers and thermocouple temperature sensors were calibrated. Each temperature sensor was calibrated at a minimum of three points over the anticipated range of use against an NIST-traceable mercury-in-glass thermometer. All sensors were calibrated prior to field sampling on a semi-annual basis. The thermocouples used in the pit were calibrated before installation and could not be recalibrated once cemented in place. Each of

TABLE 5.1. CALIBRATION FREQUENCIES, LIMITS, AND RESULTS

QA ACTIVITIES	FREQUENCY	ACCEPTANCE LIMIT	RESULTS
Post Test Leak	Each test run	<0.02 cfm or 4% of average sampling rate	All met acceptance limit
Nozzle size check	Pre-test	0.004 in variation in diameter	All nozzles passed.
Pitot calibrations	Semi-annually	EPA Method criteria for calibration and alignment	Calibrated before test and after field test
Field dry gas meter			Calibrated before test and after field test
Individual factor (Yi) for each flowrate. Average factor (y)	Pre-test and post test Semi-annually	Within (±) 2% of average factor 1.00 (±) 10%	Each gas meter passed.
Barometric pressure	Annually	Within 0.1 inches HB Class S mercury in glass barometer	Barometer passed

the Type K thermocouples used in the pit were calibrated with instruments traceable to NIST. They were calibrated at four different temperatures ranging from 40 to 350 °F. All thermocouples were within plus or minus 1 °F. Several thermocouples, along with the lead wire and junction taken at random, were placed in an oven and taken to 700 °F. No deterioration was detected.

Dry Gas Meter Calibration.

Dry gas meters (DGMs) were used in Methods 29/421/23/5 trains to monitor the sampling rate and to measure the sample volume. All dry gas meters were calibrated (documented correction factor) prior to departure of the equipment to the field. A post-test calibration check was performed which agreed with pre-test calibration to within plus or minus 5 percent.

Prior to calibration, a positive pressure leak-check of the system was performed using the procedure outlined in Section 3.3.2 of EPA Document 600/4-77-27b. The system was placed under approximately 10 inches of water pressure, and a gauge oil manometer was used to determine if a pressure decrease could be detected over a 1-minute period. Any leaks detected were eliminated before actual calibrations were performed.

After the sampling console was assembled and leak-checked, the pump was allowed to run for 15 minutes. This allowed the pump and DGM to warm up. The valve was then adjusted to obtain the desired flow rate. For the pre-test calibrations, data were collected at orifice manometer settings (delta H) of 0.5, 1.0, 1.5, 2.0, 3.0, and 4.0 inches of water pressure. Gas volumes of 5 ft^3 were used for the two lower orifice settings, and volumes of 10 ft^3 for the higher settings. The individual gas meter correction factors (Y_i) were calculated for each orifice setting and averaged. This method requires that each of the individual correction factors fall within 2 percent of the average correction factor, or the meter must be cleaned, adjusted, and recalibrated. For the post-test calibration, the meter was calibrated three times at the average orifice setting and vacuum used during the actual test.

Analytical Balance Calibration

Analytical balances were calibrated over the expected range of use with standard weights (NIST Class S). For field balances, the measured values must agree within ± 0.1 g. For laboratory analytical balances, the tolerance is ± 0.1 mg. The balances were calibrated prior to the field measurement program.

Preventive Maintenance

In addition to required calibrations, preventive maintenance was used to minimize the downtime of crucial sampling equipment due to component failure.

Prior to the field testing, all sampling systems were assembled and checked for proper operation. At this time, any worn or inoperative components were identified and replaced. In addition, an adequate inventory of spare parts was maintained to minimize equipment downtime. This inventory emphasized those parts (and supplies) which:

- Are subject to frequent failure,
- Have limited useful lifetimes, or
- Cannot be obtained in a timely manner should failure occur.

Examples of available spare parts and supplies are summarized in Table 5.2. Also, the Field Sampling Manager was responsible for maintaining contact to support unforeseen requirements and to expedite shipment of materials to the field site. Major replacement items such as meter boxes and probes were kept ready at the sampling location.

5.5.3 Laboratory Analysis

5.5.3.1 Sampling for Trace Elements

Determination of the trace elements was done using inductively coupled plasma atomic emission spectrometry (ICP-AES), for chromium, cadmium, and nickel. Atomic absorption spectrometry was used for arsenic and with cold vapor/silver amalgamate for mercury.

TABLE 5.2 LIST OF SPARE PARTS FOR FIELD SAMPLING

Train Glassware	Tubing
Pump	Thermometers
Dry Gas Meter	Various fittings
Probe sheaths	Thermocouple readouts
Heat tape	Pressure gauges/regulators
Variac	Probe liners
Thermocouples	Pitot tubes
Rotameters	Reagents
Extension cords	

The ICP-AES and atomic absorption instruments were calibrated before each analysis of sample batches. The calibration procedure described here applied to both ICP-AES and atomic absorption techniques.

Calibration consisted of analyzing standards (Baker Instra-Analyzer from J. T. Baker) of known metal concentrations prepared at three different concentration levels, and performing a linear regression calculation. Calibration standards were prepared using an acid matrix that was as close as possible to the actual samples. After calibration of the instrument, an initial calibration verification (ICV) standard was analyzed to verify that the instrument was calibrated. The ICV standard consisted of a reference material with known elemental concentration. A blank (distilled, deionized water) and a continuing calibration verification (CCV) standard (prepared by J. T. Baker Chemicals) was run at a minimum frequency of 10 percent while analyzing the samples. A percent recovery for the CCV standard of 100 ± 25 percent was considered adequate to continue with the analysis. All recoveries were within this limit. The last sample to be analyzed was a CCV standard and a blank to test for instrument drift.

5.5.3.2 Sampling for Volatile Organic Compounds

Volatile organic compounds in Summa cans were analyzed using gas chromatography/mass spectrometry (GC/MS) techniques. A multi-component mixture containing the 41 screening compounds were used to calibrate the analytical instrumentation for this analysis. The calibration mixture was derived in a high pressure cylinder (1,000 psig) at a nominal concentration of 200 ppb (each species). The cylinder was cross-referenced to several NIST standards. However, for most of the 41 components, primary standards are not available from NIST. For these compounds, the cylinder contents were referenced against standards generated by static dilution in a 17.3 m^3 Teflon®-lined environmental chamber.

The calibration cylinder was used in conjunction with a gas-phase dilution system to generate low ppb level mixtures. Humidified zero air (Aadco, Inc.) served as the diluent gas. The dilution system was equipped with mass flow controllers which were calibrated with a soap film bubble meter (referenced to NIST). The cylinder and the dilution system were used to generate a multi-point calibration curve that covered the expected concentration range of the target compounds (0 to 200 ppb). After establishing linear behavior of the instrument over the above concentration range, a single point calibration was used prior to sample analysis each day to track the performance of the GC/MS system. A 10 percent control limit was used for daily calibration checks of the GC/MS.

5.5.3.3 Sampling for Acid Gases

The determination of hydrogen chloride (as Cl^-) was performed by ion chromatography. Samples were injected using either manual injection or an autosampler. After calibrating the instrument with a minimum of three standards (J. T. Baker) prior to sample analysis, an instrument calibration verification (ICV) standard (J. T. Baker) was analyzed; CCV was also analyzed at a minimum frequency of 10 percent during sample analysis. A percent recovery within 100 ± 20 percent for the ICV and CCV standards was required. If the ICV and CCV analysis results fell outside these limits, the remedial action was reanalysis, repreparation and reanalysis, or recalibration and reanalysis. Samples yielding analysis results that are greater than 25 percent above the highest standard were diluted to fall within the limits of the calibration curve.

5.5.3.4 Sampling for Chemical Agent (Gaseous)

Single point calibrations (challenges) were performed at the beginning of each sampling day and after every 4 hours of continuous operation. Calibration standards were available for mustard concentrations to provide a challenge of 1 TWA (0.003 mg/m^3). Once each day, the Minicams underwent a complete calibration using five different concentrations. During pre-operational QA reviews, a problem with the Minicam flowmeters was found. The flowmeters used on the Minicams to measure the gas flow rate to the Minicams had expired calibrations due to delays in the project. The flowmeters were returned for calibration after the field demonstration and found to be within acceptable limits. They were all less than 1 percent from calibration, well within performance specifications. They were not returned before the test due to a long turnaround time for calibration.

5.5.3.5 Sampling for Gaseous Emissions

Continuous gas emissions were monitored at the outlet of the fume burner. The emissions monitored were oxygen, carbon monoxide, carbon dioxide, sulfur dioxide, and nitrogen oxides. Hydrocarbons were also monitored at the inlet to the fume burner. Quality assurance was maintained through routine calibration of the instruments.

Gas samples were pulled from the appropriate location through sampling lines to the continuous gas monitors. The gases were filtered and condensates were removed using liquid traps. The sampling pump moved the gases through the monitoring system. The analyzers provided a 0-1 VDC signal to the data acquisition system.

The gas flow rate to each gas analyzer was controlled by a small gas rotameter. The flow rate varies by analyzer, but was approximately 0.5 liter per minute.

The gas analyzers were calibrated twice daily. The zero was checked using high purity nitrogen. The span was checked by using a span gas mixture of SO_2, O_2, CO, CO_2, NO_x, and methane in nitrogen. The zero and span gas were connected to the sampling system by a valving arrangement so each analyzer could be calibrated. The calibration was done in the morning and evening each day, and logged in the laboratory notebook. The monitors were off-line during calibration.

The daily zeroing and spanning of the analyzers comprises the quality assurance, along with inspection of the sampling system for leaks.

Records of calibration, maintenance, and sampling system changes were documented with waterproof ink in the laboratory notebook. The data acquisition system recorded the output signals from the gas analyzers.

5.5.3.6 Sampling for Chemical Agent (Solids and Swipes)

The purpose of collecting concrete core samples and subfloor soil samples and swipes from surfaces in the pit was to detect the presence of the agent distilled mustard (HD) and its breakdown products. Nine concrete cores were obtained, six from the floor of the pit, one from each side wall of the pit, and one background sample obtained from the floor of the southernmost thaw room, which was once used for offices. Swipes samples were taken from tank, floor, and wall surfaces. In addition, two duplicate core samples were drilled next to other samples. Subfloor soil samples were collected from the bottom of each hole drilled in the concrete.

5.5.4 Sample Chain-of-Custody

All samples taken in the pit and generated from emissions monitoring were taken according to the Sampling and Analysis Plan. The swipe samples used analytical-grade hexane on sterile gauze. Several process blanks were taken during the swipe sampling process and submitted for analysis. The swipe blanks were gauze pads wet with hexane and placed into the sample bottle without contacting any surface in the pit. The swipe samples were placed into certified clean glass jars, labeled with a sample label, and taped shut with Teflon® tape followed by electrical tape. The samples were listed on a

Chain-of-Custody (COC) form and placed in a cooler that was sealed with tamper-proof tape. Similar procedures were done with all the other samples generated from the field demonstration test.

5.6 DATA REDUCTION, VALIDATION, AND REPORTING

Data validation consists of verification of calculation methodology; consistency of raw, reduced, and summarized data tables; comparison to expected results; and consistency of results among multiple measurements at the same location.

Field sampling data was validated initially by the Field Manager based on his judgement of the representativeness of the sample, maintenance and cleanliness of sampling equipment, and adherence to sample collection procedures defined in the Sampling and Analysis Plan. The field manager also validated the data on a daily basis based on: (1) process conditions during sampling or testing, (2) adherence to the acceptance criteria given in the Sampling and Analysis Plan, and (3) acceptable performance evaluation and technical system audit results conducted by project staff.

When the data set was completed, the Field Manager performed an overall review of the data. This review considered (1) the above criteria, and (2) the consistency and reasonableness based on a knowledge of the site characteristics and the specific location of individual samples. The review also included an evaluation of the data in terms of the quality assurance objectives outlined in the Sampling and Analysis Plan. The quality control criteria for data validation included data consistency, duplicate samples, solvent blanks, solvent with spikes, tests for outliers, and transmittal errors.

6.0 RESULTS AND DISCUSSION

6.1 SAMPLING AND ANALYSIS RESULTS

Several types of samples were taken in the mustard pit before and after the field demonstration, to verify the effectiveness of the Hot Gas process. These include concrete core samples in the floor and ventilation tunnel (west of the pit), soil samples beneath the floor, paint and wipe samples from the tanks, and samples of liquid in the sump. Figure 6.1 shows the location of the baseline and post-operation samples taken in the mustard pit. The post-operation samples were located within 12 inches of the baseline samples to provide an accurate comparison.

It is noted that the soil beneath the mustard pit was not included in the target area for decontamination in the field demonstration of the HGDS. However, since the soil near the concrete was subjected to heat from the process, sampling and analysis was performed on the soil to evaluate the effects of the Hot Gas process.

No mustard agent was detected in the concrete, soils or tank surfaces after the field demonstration, while the original baseline samples indicated a substantial amount present. Even though the baseline samples were taken five years prior to this field test, the persistence of the contamination is evident from the time of last active H operations (1974) in the Building 537 pit to the time of sampling (1989). A comparison of results of the baseline and post-operation analytical testing for mustard agent and its primary byproducts (oxathiane and dithiane) is presented in Table 6.1. This information indicates that the Hot Gas process was effective in fully decontaminating the target from mustard agent. It is noted that by-products remained in low concentrations after the field demonstration.

Sample Collection

A period of four days was allowed after shutdown for the pit to cool before the samples were taken. This permitted the mustard pit to return to near-ambient temperatures, as required for intrusive concrete and soil boring

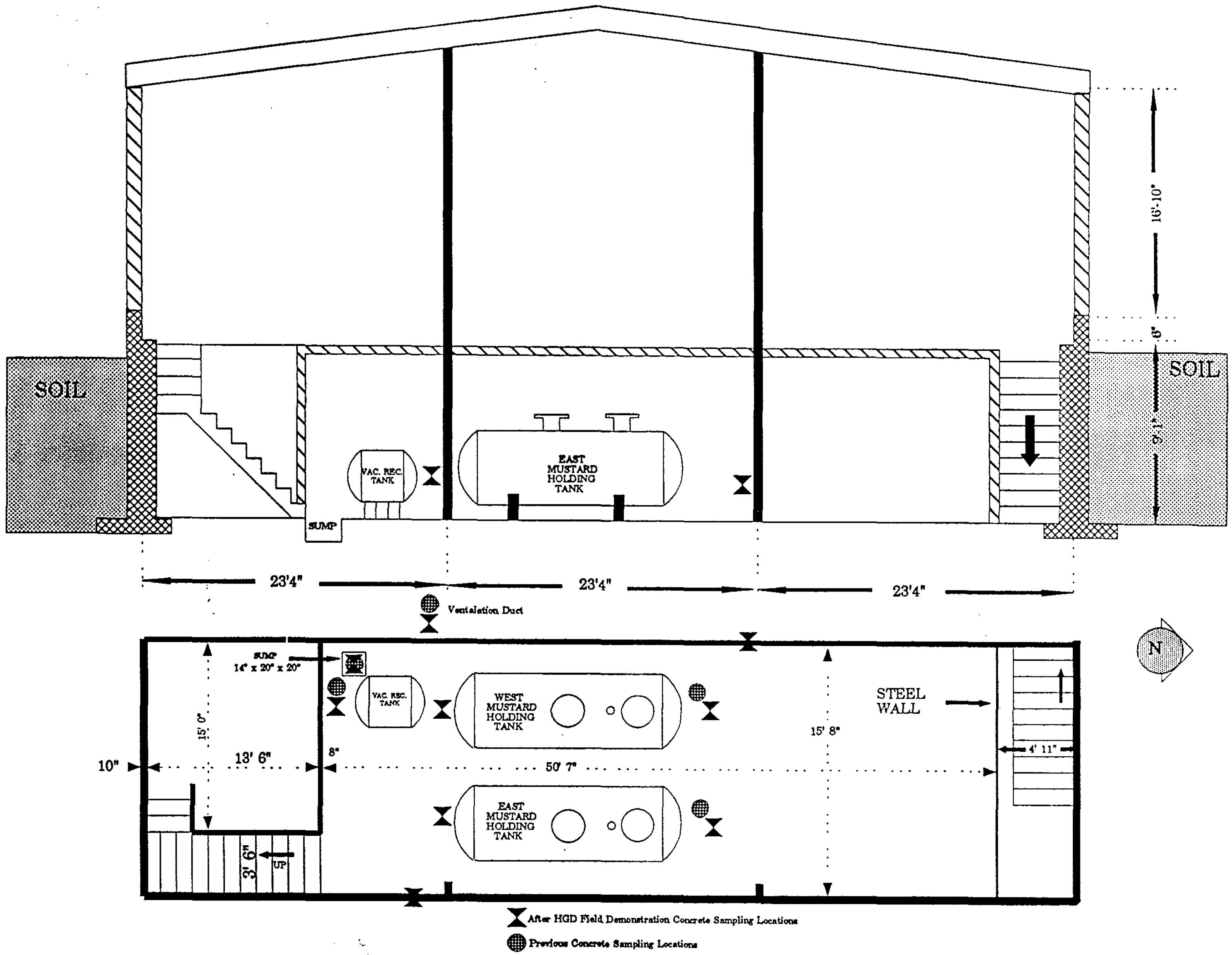


Figure 6.1 Core Sampling Locations

TABLE 6.1 ANALYSIS BEFORE AND AFTER HGDS TEST

Type of Sample	Location	Before**			After		
		HD μg/g	Oxathiane μg/g	Dithiane μg/g	HD μg/g	Oxathiane μg/g	Dithiane μg/g
Paint	Vacuum tank	8.71	2.16	6.35	MQL	<MQL	<MQL
Wipe	North end West tank	BQL	BQL	3.52	MQL	<MQL	<MQL
Wipe	North end East tank	BQL	BQL	BQL	MQL	<MQL	<MQL
Concrete	East of sump	BCRL/1.4/3.3	0.63/1.4/.93	5.2/12/20	MQL	<MQL	<MQL
Soil	East of sump	96	.13	23	MQL	1.41/1.23/0.70	5.29/4.22/4.78
Liquid (before) solid (after)	Sump	2804*	BQL	461*	MQL	<MQL/2	<MQL
Concrete	North of West tank	BQL/18/45	BQL/7.4/11	BQL/13/30			
Soil	North of West tank	BCRL	3.9	38	MQL	0.1/0.19/1.91	0.69/1.40/7.85
Concrete	North end of East tank	3.79	BQL	0.46	MQL	<MQL/0.35/.16	<MQL/0.39/ 0.12
Concrete	Ventilation duct	BCRL	0.50	0.62	MQL	1.00	2.00
Soil	Ventilation duct	BCRL/BCRL	BQL/BQL	BQL/BQL	MQL	<MQL	<MQL

* Sample diluted 1:1000.
** Analysis performed in 1989.
† Where multiple numbers appear, they correspond to top/middle/bottom or top/bottom of sample.
BQL = Below Quantitation Limit (HD and Oxathiane = 0.19 μg/gm, dithiane 0.095 μg/gm). (1989 Test).
BCRL = Below Certified Reporting Limit (1.79 μg/g HD) using USATHAMA QA/QC Program (1 April 1988).
MQL = Minimum Quantification Level of HD is 0.5 μg/gm. MQL of Dithiane and Oxathiane is 0.1 μg/gm.

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sample collection. Swipe samples from the surfaces within the mustard pit were also collected for analysis.

Concrete and soil samples were retrieved using a 2 inch core and were placed in stainless steel sleeves, labeled, and tagged with chain-of-custody (COC) labels. Swipe samples were collected in certified clean amber glass wide-mouth jars, and were labeled and tagged with COC labels. The samples were then transported in a COC tagged insulated container to Building 1710 (TVA Operations Center) for temporary storage for 20 days in a refrigeration unit at 4 °C. The samples were transported by the analytical staff to the RMA Analytical Agent Laboratory (AAL) for unpacking, inventory, photographic recording, extraction, and analysis. COC reports for each sample were maintained throughout the sampling, transportation, unpacking, and analysis phases.

Sample Extraction and Analysis

All samples collected underwent extraction procedures in the RMA AAL. The discussion of the sample extractions and subsequent analyses is divided into the following three sections: 1) Swipe Sample Extraction and Analysis, 2) Concrete Core Sample Extraction and Analysis, and 3) Soil Sample Extraction and Analysis.

Swipe Sample Analysis

Swipe samples were unpacked and inventoried in the RMA AAL. Each swipe sample consisted of one 2" x 2" section of 12-ply medical gauze completely submerged in a 10 mL solution of analytical-grade hexane. Each swipe sample was treated in the same manner, during both sampling and analysis. Sample jars were vortexed for a period of 30 seconds, followed by a 5 minute "settling" period. Three 1 mL aliquots were then transferred into three 1.2 mL amber glass gas chromatograph vials and sealed with Teflon septa caps. The first of the three vials was used for HD analysis by Gas Chromatograph (GC), the second for HD by-product analysis, and the third retained as an archive sample.

All swipe samples were analyzed for HD by Gas Chromatograph-Flame Photometric Detector (GC-FPD) on a Hewlett-Packard® 5890 Series II GC.

Prior to analysis of the swipe samples, the GC was calibrated with standards in a solution of analytical-grade hexane at the following concentrations: 0.5 μg/mL, 1.0 μg/mL, 2.5 μg/mL, 5.0 μg/mL, and 10.0 μg/mL.

Calibration standards were formulated using the following procedure. A 1.0 mL solution of 5.14 mg/mL HD Chemical Agent Surety Analytical Reference Material (CASARM) Stock solution was obtained from the RMA AAL Exempt Dilute Solution (XDS) custodian prior to the formulation of each calibration solution lot. A total of 10 mL of each calibration standard concentration lot was formulated at a time.

Samples were analyzed on the GC in the following sequence: Calibration Curve, Solvent Blank, Spiked Blank, Sample 1, Sample 2, Sample 3, Sample 4, Calibration Standard, Samples 5, 6, 7, 8, etc.

6.1.1 Swipe Sample HD Analysis Results

The samples analyzed for the presence of HD were all less than (below) the Minimum Quantitation Level (MQL) (0.5 μg/gram). The HD by-products were detected at levels within the calibration range (0.1 μg/gram to 7.0 μg/gram) or they were not detected above the MQL (0.1 μg/gram for Oxathiane and Dithiane). Data from the swipe sample analyses is presented in Table 6.2.

Swipe Sample HD Byproduct Analysis

All swipe samples were analyzed for HD by-products by GC-FPD (sulfur mode) on the Hewlet-Packard® 5890 Series II GC. The samples were analyzed as described above for the swipe sample HD analysis.

Prior to the analysis, the GC was calibrated with standards suspended in a solution of analytical grade Hexane. The calibration standards were prepared from a 1.0 mL aliquot of 10.09 mg/L stock HD by-product solution.

All calibration standards were formulated using the following process:

A 1.0 mL solution of 5.14mg/mL HD CASARM Stock solution was obtained from the RMA AAL Exempt Dilute Solution custodian prior to the formulation of each calibration solution lot. A total of 10 mL of each calibration standard concentration lot were formulated at one time. The calibration stock solutions were created using the following dilution formulas:

0.5 μg/mL = 1.0 μL (5.14 mg/mL) into 10.0 mL Hexane
1.0 μg/mL = 1.9 μL (5.14 mg/mL) into 10.0 mL Hexane
2.5 μg/mL = 4.9 μL (5.14 mg/mL) into 10.0 mL Hexane
5.0 μg/mL = 9.7 μL (5.14 mg/mL) into 10.0 mL Hexane
10.0 μg/mL = 19.5 μL (5.14 mg/mL) into 10.0 mL Hexane

Prior to analysis of the HD by-product samples, the GC was first calibrated with standards suspended in a solution of analytical grade Hexane. The calibration standards were prepared from a 1.0 mL aliquot of 10.09 mg/L stock HD by-product solution provided by the technical staff of the RMA AAL. The calibration solutions were prepared as follows:

0.5 μg/mL = 250 μL (10.09 mg/L) into 5.0 mL Hexane
1.0 μg/mL = 500 μL (10.09 mg/L) into 5.0 mL Hexane
2.5 μg/mL = 1250 μL (10.09 mg/L) into 5.0 mL Hexane
5.0 μg/mL = 500 μL (10.09 mg/L) into 500 μL Hexane
7.0 μg/mL = 700 μL (10.09 mg/L) into 300 μL Hexane

Samples were analyzed on the GC in the following sequence: 5 Point Calibration Curve, Solvent Blank, Sample 1, Sample 2, Sample 3, Sample 4, Calibration Standard, Samples 5, 6, 7, 8 on ascending in numerical order.

The results of the swipe sample analysis was within acceptable ranges, and no problems were encountered during the analysis. No detectable levels of HD by-product contamination were found in any swipe sample. Table 6.2 presents the analytical results for the swipe sample HD by-product analysis.

6.1.2 Concrete Core Sample HD Extraction

Concrete core samples were unpacked and inventoried in the RMA AAL. All sample sleeves were intact with COC seals in place. Each sleeve was opened at the top, and the contents were emptied onto a plastic-backed absorbant pad. Observations of the contents were noted in the Laboratory Record Notebook (LRB) Number 46882 (pp. 46882-91 to 46882-95). Concrete cores were segregated into three distinct layers, labeled "I", "II", and "III", which correspond to the "Top", "Middle", and "Bottom" of the core section respectively. A description of each concrete sample is presented in Table 6.3.

The time duration between when the samples were collected and when these samples were analyzed was 20 days. All samples analyzed which contained the

TABLE 6.2 (1 OF 2) SWIPE SAMPLE DATA

Sample Type	Lab Record Book ID	Description of Location for Sample Removal	Time Tested	Date Tested	HD Result	Dithiane Result	Oxathiane Result
Swipe	46882-78-10	North down corner of plenum	10:00	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-78-12	First floor panel removed, surface next to concrete, North end of West tank panel	10:10	4/13/84	<MQL	<MQL	<MQL
Swipe	46882-78-14	Inner surface of plenum, 3rd panel from North end on East wall, chest high	10:15	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-78-16	Floor panel, surface to concrete North end of East tank	10:25	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-78-18	Process Blank - when carrying samples up and down North stairs	10:30	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-78-20	Between corrugated and flute plate on Northwest wall North of West tank, taken on flute plate center	10:40	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-78-22	North end of East tank near top	10:45	4/13/94	<MQL	<MQL	<MQL

1. Minimum Quantification Level (MQL) of HD is 0.5 μg/gm. MQL of Dithiane and Oxathiane is 0.1 μg/gm.

TABLE 6.2 (2 OF 2) SWIPE SAMPLE DATA

Sample Type	Lab Record Book ID	Description of Location for Sample Removal	Time Tested	Date Tested	HD Result	Dithiane Result	Oxathiane Result
Swipe	47882-78-24	Metal plate, flat, center, surface to concrete, West wall	10:55	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-78-26	North end of West tank, near top	11:05	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-78-28	South end, center, corrugated surface in plenum	12:15	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-78-30	South end of East tank near top	12:20	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-79-2	South end of Vacuum tank near top	12:26	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-79-4	Paint sample off South end of Vacuum tank	12:30	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-79-6	Process Blank - South end, with everything in pit	12:35	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-79-8	Floor, metal, dusty surface of plenum South of West tank	12:40	4/13/94	<MQL	<MQL	<MQL
Swipe	46882-79-10	Blank - out of Building 537 using materials from pit, South, Sampling	13:00	4/13/94	<MQL	<MQL	<MQL

1. Minimum Quantification Level (MQL) of HD is 0.5 μg/gm. MQL of Dithiane and Oxathiane is 0.1 μg/gm.

TABLE 6.3 CONCRETE CORE OBSERVATIONS

77-15 Each layer (section) consisted of a 6 inch piece of concrete core, beige in color. The bottom core piece was somewhat moist.

80-19 (I) 6 inch piece of concrete core, beige in color, containing particles of red rock. (II) - outside layers of sample are light brown. (III) - outside of sample is beige containing particles of red rock, inside of sample is black in color and moist in consistency.

80-21 (I) Many small pieces of concrete, beige in color, containing particles of red rock. (II) Small pieces of concrete, beige in color, containing particles of red rock. (III) Small pieces of concrete, beige in color, containing particles of red rock.

80-23 (I) - 3 inch piece of concrete, beige on the outside, beige and containing red rock on the inside. (II) - 3 inch piece of concrete, beige outside, beige and containing black rocks on the inside. (III) - 3 inch piece of concrete, beige outside, moist and light brown inside.

80-28 (I) - 1-3 inch piece of beige concrete. (II) - Several black colored rocks. (III) 1-3 inch piece of beige concrete.

81-1 (I),(II), (III) - All three samples were a 3 inch piece of concrete with red rocks embedded.

81-6 (I) - 6 inch piece of concrete containing red rock. (II) - A white 6 inch piece of concrete containing some colored rock. (III) - 3 inch piece of concrete dark beige in color.

81-11 (1) - 6 inch piece of concrete containing small colored rocks. (II) - Blackish concrete material. (III) - 6 inch piece of concrete containing a few colored rocks.

82-2 (I), (II), (III) - This core sample consisted of a 12 inch piece. The sample was broken into 3 pieces. Samples were beige in color and contained rocks.

82-4 (I) - 3 inch piece of concrete, beige in color. (II) - 3 inch piece of concrete beige in color, containing colored rocks.

82-6 Samples taken from 2-8 inch pieces of concrete containing colored rocks.

82-9 Sample I, II, and III taken from one 8 inch piece of concrete and one 6 inch piece of concrete. Core samples contained sand in them.

82-12 Treated painted end of sample as top. Beige in color and containing rocks. Not labeled as to top and bottom of sample.

82-14 Three 3 inch pieces of concrete containing colored rock. Samples also contained black rock.

"amber/yellow" contaminant were submitted for analysis via GC/MS to determine the identity of this contaminant and since the contaminant interfered with GC analysis. This procedure was followed for all sample matrices.

Approximately 12.0 grams of core material was removed from each layer by a chisel and hammer. The samples were crushed by a custom-made pulverizing unit constructed of stainless steel.

A 10.0 mL solution of Analytical Grade Chloroform (B&J Brand procured in Denver) was added to each 10.0 gram layer sample. The mixture was agitated by vortex for a period of 30 seconds and then allowed to settle for a period of 15 minutes. A 300 μL aliquot was collected by syringe from each sample solution. The syringe was then fitted with a 0.45um filter paper (ALLTECH Lot No. G077031) in a syringe adaptor. Then a 1.0 mL of the solution in the syringe was transferred into three 1.2 mL Amber GC vials. As noted above, one vial was used for HD analysis, one vial for HD By-Product analysis and one vial was stored as an archive sample. This was performed for each layer of each sample point.

Approximately thirty percent of the extracted samples appeared to have an amber/yellow color, despite the fact that all extractions were made under identical conditions. The amber/yellow color was similar to the color of the HD soil sample extracts. The middle layer of each colored sample was submitted for mass spectral analysis, to identify the source of the amber/yellow color and to search for other possible target analytes. The rationale not to analyze every layer from each sample was predicated upon the amount of time required to perform the analyses and operator availability. The source was found to be long chain hydrocarbon contamination, and was the same as in the soil samples.

Concrete Core Sample HD Analysis

Concrete core samples were analyzed utilizing the same methods as previously described for swipe samples. Calibration standards used in the analysis of the concrete core samples were prepared the same as for HD analysis of the swipe samples, with the exception that they used an analytical grade of chloroform instead of hexane. Chloroform standards were produced in an identical fashion to hexane standards with the exception of using the chloroform solvent instead of the hexane solvent. The GC was calibrated using the same concentrations and sequence as described for swipe sample HD analysis.

All samples which exhibited the amber/yellow color following extraction were analyzed by mass spectral instrumentation.

The analysis of the concrete core samples by either GC-FPD or by mass spectral analysis proceeded without difficulty. The samples indicated no detectable HD contamination. Estimated values for the GC/MS analyses were less than 4.0 μg/gram for HD and 10.0 μg/gram for all HD by-products. Data for HD analysis of the concrete core samples is presented in Table 6.4. Mass spectral analysis is capable of accurately quantifying HD concentrations ≥ 4 μg/gm. Below this threshold, RMA analytical staff estimated the concentration values.

Concrete Core Sample HD By-Product Analysis

The concrete core samples were analyzed for HD byproducts in the same manner as previously indicated. All calibration standards were prepared with chloroform. The sample run sequence is identical to the one described above. Several concrete core samples contained varying quantities of oxathiane and dithiane (both HD breakdown components) when analyzed by either GC-FPD or by mass spectral analysis. Mass spectral analysis is capable of accurately quantifying concentrations of target compounds when in concentrations greater than 10 μg/gram. Below this threshold, the RMA Analytical staff estimated the concentration values. Laboratory results are presented in Table 6.4.

Soil Core Sample HD Extraction

The number of stainless steel sleeves noted on the COC inventory documentation matched the number of sleeves which were unpacked. Each sleeve was opened at the end of the sleeve marked "Top" and the contents were emptied onto a plastic backed absorbent pad. A description of each soil sample and

TABLE 6.4 (1 OF 3) CONCRETE CORE SAMPLE DATA

Sample Type	Lab Record Book ID	Description of Location for Sample Removal	Time Tested	Date Tested	HD Result	Dithiane Result	Oxathiane Result
Concrete	48882-80-19	Concrete core #2 14" east of sump	09:00	4/15/94	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL
Concrete	48882-80-21	Concrete core #3 east wall south of tanks, approximately 24" from floor, hit rebar and stopped drilling	10:15	4/15/94	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL
Concrete	48882-80-23	Concrete core #3 east wall - Tried redrilling a few inches over from above hole and hit rebar again and stopped drilling on east wall, will analyze concrete cores	10:15	4/15/94	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL
Concrete	48882-80-28	Concrete core from floor south end of east tank	11:10	4/15/94	I=<MQL II=<MQL III=<MQL	I=1.11 II=5.36 III=7.58	I=0.17 II=0.71 III=0.62
Concrete	48882-81-1	Concrete core south end of west tank, sample got ground up in core bit	13:05	4/15/94	I=<MQL II=<MQL III=<MQL	I=0.83 II=0.51 III=8.17	I=0.13 II=<MQL III=0.37
Concrete	48882-81-4	Second concrete core east of sump	13:25	4/15/94	No data available	No data available	No data available
Concrete	48882-81-6	North end of west tank - Two cores in tube, 1st is start of core - moved drill and started again - blue cap separates samples of concrete core	14:00	4/15/94	No Data Available	No Data Available	No Data Available

Notes:

1. Minimum Quantification Level (MQL) of HD is 0.5 μg/gm. MQL of Dithiane and Oxathiane is 0.1 μg/gm.
2. Samples marked for Mass Spec (MS) analysis were obtained from the middle layer of the samples submitted. Results <10 μg/gm for by products are approximates. Results for HD reported at <4 μg/gm. Sample results labeled I, II, and III correspond to top, middle, and bottom of each core sample respectively.

TABLE 6.4 (2 OF 3) CONCRETE CORE SAMPLE DATA

Sample Type	Lab Record Book ID	Description of Location for Sample Removal	Time Tested	Date Tested	HD Result	Dithiane Result	Oxathiane Result
Concrete	48882-81-11	North end of east tank	14:40	4/15/94	I=<MQL II=<MQL III=<MQL	I=<MQL II=0.39 III=0.12	I=<MQL II=0.35 III=0.16
Concrete	48882-81-18	Took a small sample of material - sample was "sniffed" by MINICAMS and showed only low background readings	14:55	4/15/94	MS <MQL	MS <MQL	MS <MQL
Concrete	48882-81-22	Also took sample of ground up concrete from hole east of sump - many of the lower floors in the pit ground up as a black material - when some of the core material remained in one piece the concrete was black	15:20	4/15/94	MS <MQL	MS <MQL	MS <MQL
Concrete	48882-81-28	Took bottle sample of sump material	15:30	4/15/94	MS <MQL	MS <MQL	MS <MQL
Concrete	48882-82-2	Concrete core of west wall north of west tank - drilled until we hit rebar	08:15	4/16/94	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL

Notes:
1. Minimum Quantification Level (MQL) of HD is 0.5 μg/gm. MQL of Dithiane and Oxathiane is 0.1 μg/gm.
2. Samples marked for Mass Spec (MS) analysis were obtained from the middle layer of the samples submitted. Results <10 μg/gm for by products are approximates. Results for HD reported at <4 μg/gm. Sample results labeled I, II, and III correspond to top, middle, and bottom of each core sample respectively.

TABLE 6.4 (3 OF 3) CONCRETE CORE SAMPLE DATA

Sample Type	Lab Record Book ID	Description of Location for Sample Removal	Time Tested	Date Tested	HD Result	Dithiane Result	Oxathiane Result
Concrete	48882-82-4	Same as above but approximately 4" north and 4" higher - hit rebar again	08:45	4/16/94	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL	I=<MQL II=<MQL III=<MQL
Concrete	48882-82-6	Redrilled above but only 4" above first hole - got through concrete to under ventilation duct	09:15	4/16/94	MS <MQL	MS <MQL	MS <MQL
Concrete	48882-82-9	Concrete core in ventilation duct - lost bottom of core to large cavity below concrete - got good top section	10:30	4/16/94	MS <MQL	MS 1.00 µg/gm	MS 2.00 µg/gm
Concrete	48882-82-12	Floor core of office area of Building 537 - Use as a blank	13:13	4/16/94	No Data Available	No Data Available	No Data Available
Concrete	48882-82-14	Redrill of sump - Drilled approximately 8" hit a rebar moved drill and redrilled with different bit - drilled as far as we could and hit hard material again - not a good core - material did smell - drilled approximately 18".	14:30	4/16/94	MS <MQL	MS 16 µg/gm	MS 4 µg/gm

Notes:

1. Minimum Quantification Level (MQL) of HD is 0.5 µg/gm. MQL of Dithiane and Oxathiane is 0.1 µg/gm.
2. Samples marked for Mass Spec (MS) analysis were obtained from the middle layer of the samples submitted. Results <10 µg/gm for by products are approximates. Results for HD reported at <4 µg/gm. Sample results labeled I, II, and III correspond to top, middle, and bottom of each core sample respectively.

recorded weights is presented in Table 6.5. The color and conditions of the samples are noted in the Laboratory Notebook (LRB) Number 46882 (pp. 46882-84 to 46882-89). Unlike the concrete core samples, distinctive layers were not observed in the samples. In order to facilitate sample identification, each soil sample was divided into three layers, 6 inches in length. These were the Top, Middle, and Bottom layers similar to those used for the concrete core samples. A 10.0 gram (±0.1 gram) sample was removed from each layer and transferred into a tared 4 dram vial. Each layer was extracted by adding 10.0 mL of analytical-grade chloroform to the vial and agitating for 30 seconds. The sample was allowed to settle for 15 minutes. A 3 mL aliquot was then collected by syringe from each sample solution. The syringe was then fitted with 0.45um filter paper (ALLTECH Lot No. G077031) in a syringe adaptor. A 1.0 mL of the solution in the syringe was then transferred into a three 1.2 mL Amber GC vials. As noted above, one vial was used for HD analysis, one vial for HD by-Product analysis and one vial was stored as an archive sample. This was performed for each layer of each sample point.

During the soil core sample extraction process, approximately 50% of the samples appeared to have a amber/yellow color. The remaining extracts appeared as clear solutions.

TABLE 6.5 SOIL CORE OBSERVATIONS

80-2 Soil appears wet and sandy. Very packed in collection vessel. Soil appears drier at the top of the sample than at the bottom of the sample. Light brown in color.

80-5 Soil darker in color than sample 80-2. Soil appears soft. Bottom layer of sample drier than top layer. Sample appears sandy. Medium brown in color.

80-8 Very sandy, dry on top layer. Dark brown in appearance. Middle of sample is lighter than top of sample. Bottom of sample is very wet, dense, and has a clay-like consistency.

80-10 Top of sample very wet, light in color. Middle of sample was not as wet, and color was lighter than top layer of sample. Bottom layer of

TABLE 6.5 SOIL CORE OBSERVATIONS (Cont'd)

sample was much lighter than the first two layers, and had a very hard, dry consistency.

80-12 Top layer of sample was very wet and dark brown in color. The middle layer was similar to the top layer in appearance and color. Bottom layer of sample was sandy and light in color.

80-14 Sample consists of a sump material. Very dry, dark black in color. Sample is hard.

80-16 Sample had a sandy consistency and was full of large rocks. Sample was wet throughout.

81-18 Sample labeled as "drill material". Sample was very wet and slimy. Sample was reddish brown in color.

81-22 Sample labeled as "ground concrete". Sample appeared moist and sandy. Sample was blackish in color.

81-28 Sample labeled as "sump material". Sample was dry with a black color.

82-20 Top layer of sample was wet and slimy, and was reddish-brown in appearance. The middle layer of the sample was drier than the top layer, but similar in color. The bottom layer of the sample was drier than the other two layers, slightly damp, and similar in color to the other two layers.

82-21 Top layer of sample very wet and slimy. Top layer was blackish brown in color. Water was noted to be standing in the sample. Middle layer of sample was drier and lighter in color than the top layer. Bottom layer of sample was wetter than middle layer but not as wet as top layer. This layer was brownish in color.

82-22 Sample not labeled as to top and bottom. Core sample was very dry, sandy, and brown.

Soil Core HD Sample Analysis

Samples in the first set were initially analyzed by GC-FPD. An interferant was present which masked the critical HD "gate" and prevented accurate sample analysis. Samples with the amber/yellow color contained the interferant in question. These samples were segregated and only the clear samples were analyzed for HD. Mass spectral analysis indicated high levels of long chain hydrocarbons were present in only the amber/yellow samples. Again, only the middle layer of the amber/yellow samples was submitted to mass spectral analysis due to time constraints and operator availability.

The long chain hydrocarbon contamination which was detected contained sulfur compounds which eluted at approximately the same time as the HD "gate" and thereby resulted in the "masking" of this critical gate. Additionally, the technical staff noted a high degree of "carry over" between samples containing the amber/yellow contaminant which supported their decision to submit these samples for further analysis via GC/MS. Although it is not documented in the report, several of the chemists at RMA indicated that this was a "common" contaminant due to the fact that diesel fuel was used in the past as a decontaminant for HD spills.

Soil core samples were analyzed at the same instrument conditions as previously described. Calibration standards used for soil core analysis were prepared the same as in the HD analysis of the swipe samples, except that standards used an analytical grade of chloroform instead of hexane.

The analysis of the soil core samples by GC-FPD and mass spectral analysis proceeded smoothly, after the segregation of amber/yellow sample extracts. The samples indicated no detectable HD contamination. The results of the soil core sample HD analyses are presented in Table 6.6.

Soil Core Sample HD By-Product Analysis

The soil core samples were analyzed for HD by-products the same as described for by-products in the concrete cores. All calibration standards were prepared in the same manner as noted before in this report with the exception that they were prepared using analytical grade chloroform instead of hexane.

TABLE 6.6 (1 OF 2) SOIL CORE SAMPLE DATA

Sample Type	Lab Record Book ID	Description of Location for Sample Removal	Time Tested	Date Tested	HD Result	Dithiane Result	Oxathiane Result
Soil	48882-82-20	Soil sample from vent duct through core hole.	10:45	4/16/94	I = <MQL II = <MQL III = <MQL	MS <MQL	MS <MQL
Soil	48882-82-21	Soil sample from Office core hole	15:00	4/16/94	MS <MQL	MS <MQL	I = <MQL II = <MQL III = <MQL
Soil	48882-82-22	Soil sample from West wall core - very dry material	09:30	4/16/94	MS <MQL	MS <MQL	MS <MQL
Soil	48882-80-2	Soil sample from concrete hole core taken from office	07:20	4/14/94	MS <MQL	MS <MQL	MS <MQL

NOTE:

1. Minimum Quantification Level (MQL) of HD is 0.5 µg/gm. MQL of Dithiane and Oxathiane is 0.1 µg/gm.
2. Samples marked for Mass Spec (MS) analysis were obtained from the middle layer of the samples submitted. Results < 10 µg/gm for by-products are approximates. Results for HD reported as < 4 µg/gm. Sample results labeled I, II, and III correspond to top, middle, and bottom of each core sample respectively.

TABLE 6.6 (2 OF 2) SOIL CORE SAMPLE DATA

Sample Type	Lab Record Book ID	Description of Location for Sample Removal	Time Tested	Date Tested	HD Result	Dithiane Result	Oxathiane Result
Soil	48882-80-5	Soil sample from South end of East tank	09:30	4/15/94	MS <MQL	MS 454.6 µg/gm	MS 11.4 µg/gm
Soil	48882-80-8	Soil sample taken from South end of West tank	10:00	4/15/94	MS <MQL	MS 1708 µg/gm	MS 23.7 µg/gm
Soil	48882-80-10	Soil sample taken from North end of East tank	10:30	4/15/94	I=<MQL II=<MQL III=<MQL	I=6.16 II=8.77 III=10.42	I=<MQL II=6.50 III=7.13
Soil	48882-80-12	Soil sample from North end of West tank	11:00	4/15/94	I=<MQL II=<MQL III=<MQL	I=0.69 II=1.40 III=7.85	I=0.10 II=0.19 III=1.81
Soil	48882-80-14	Sump material above concrete	11:15	4/15/94	MS <MQL	MS 2 µg/gm	MS <MQL
Soil	48882-80-16	Soil sample from the hole East of sump, large gap next to sump	13:00	4/15/94	I=<MQL II=<MQL III=<MQL	I=5.29 II=4.22 III=4.74	I=1.41 II=1.23 III=0.70

Notes:

1. Minimum Quantification Level (MQL) of HD is 0.5 µg/gm. MQL of Dithiane and Oxathiane is 0.1 µg/gm.
2. Samples marked for Mass Spec (MS) analysis were obtained from the middle layer of the samples submitted. Results < 10 µg/gm for by-products are approximates. Results for HD reported as < 4 µg/gm. Sample results labeled I, II, and III correspond to top, middle, and bottom of each core sample respectively.

Several soil core samples contained varying quantities of oxathiane and dithiane (both are HD breakdown components) when analyzed by either GC-FPD or mass spectral analysis. Mass spectral analysis is capable of accurately quantifying concentrations of target compounds only in concentrations greater than 10 $\mu g/gm$. Below this threshold, the RMA analytical staff estimated the concentration values. HD by-product results are summarized in Table 6.6.

6.2 EMISSIONS RESULTS

6.2.1 Stack Monitoring

Stack monitoring was conducted as an indicator of total system performance.

A tabulation of the data from Method 5 and Modified Method 5 emission sampling performed during the field demonstration is presented in Tables 6.7 through 6.9. No detectable HD contamination was observed in the stack emissions. The particulate, acid gases, metals, and organics concentrations in the stack discharge were extremely low. During pre-operational testing with the pit off-line, a background level for stack emissions was established for comparison with the pit on-line. For the entire HGDS operation from pre-operational testing through cooldown, organics were detected in the 4 ppm range. This indicates that the organics detected in the stack gases originate from the HGDS system itself (unburned hydrocarbons in fuel gas) and not from the pit. The same is true for particulates and metals, which were detected in relatively constant low levels from pre-operations through cooldown, indicating that these were background levels (presumably picked up in the combustion air and in-leakage). The one constituent which showed an increase from background during heatup was HCl, which results from the volatilization of mustard and its destruction in the fume burner to HCl, as expected.

The summa can samples also showed very low levels of organics. The most prevalent was methylene chloride, which originated from the solvent used to prepare the XAD-2 sorbent cartridge.

Table 6.7 Particulate and Metals Emissions for HGD.

	Background	Background	Heat-up	Heat-up	Heat-up	24 Hr Soak	24 Hr Soak	Cool Down	Cool Down
Run No.	1	2	3	4	5	6	7	8	9
Test Date	2/25	2/25	3/4	3/4	3/4	3/19	3/19	3/19	3/19
Volume of gas samples, DSCF	39.3	35.2	30.5	31.3	31.4	31.1	32.6	32.5	34.6
Moisture fraction volume, percent	3.1	2.8	5.6	3.9	4.8	5.1	3.8	3.5	3.7
Average stack temperature, F	401	407	410	416	414	375	380	468	472
Stack volumetric flow rate, DSCFM	5500	5396	4505	4393	4394	4444	4421	4718	4777
Stack volumetric flow rate, ACFM	10755	10589	9111	8781	8849	8680	8574	10099	10290
Isokinetic rate, percent	107.5	102.3	101.8	99.8	107.5	105.3	111.7	95.8	109.8
Particulate mass - probe, CYC, filter catch, mg	4.0	9.3	46.5	10.5	2.6	4.5	2.2	0.1	0.8
Particulate loading, GR/DSCF	0.002	0.004	0.023	0.005	0.001	0.002	0.001	0.000	0.000
Particulate loading, GR/ACF	0.001	0.002	0.012	0.003	0.001	0.001	0.001	0.000	0.000
Particulate emissions, lb/hr	0.1	0.2	0.9	0.2	0.0	0.1	0.0	0.0	0.0
Particulate loading, mg/NCM	3.6	9.3	53.9	11.9	3.0	5.1	2.3	0.1	0.8
Metals mass, mg	0.032	0.034	0.026	0.049	0.07	0.022	0.019	0.026	0.027
Metals loading, mg/NCM	0.029	0.034	0.030	0.056	0.079	0.025	0.021	0.028	0.028

Table 6.8 HCl Emissions for HGD

	Background	Background	Heat-up	Heat-up	Heat-up	24 Hr Soak	24 Hr Soak	Cool Down	Cool Down
Run No.	1	2	3	4	5	6	7	8	9
Test Date	2/25	2/25	3/4	3/4	3/4	3/18	3/18	3/19	3/19
Volume of gas samples, DSCF	37.1	41.2	44.5	29.5	29.0	30.9	37.0	33.5	34.0
Moisture fraction volume, percent	2.5	2.7	4.1	4.0	4.1	3.9	3.4	4.0	3.6
Average stack temperature, F	394	398	421	420	425	356	362	435	441
Stack volumetric flow rate, DSCFM	5545	5539	4274	4283	4119	4541	4454	4879	4916
Stack volumetric flow rate, ACFM	10691	10746	8637	8611	8343	8545	8403	10162	10271
Isokinetic rate, percent	100.8	116.6	96.8	95.6	98.7	102.2	116.4	103.2	96.7
HCl mass - impinger catch, mg	0.3	0.2	17.9	11.4	14.6	0.0	7.3	1.2	0.8
Particulate loading, GR/DSCF	0.000	0.000	0.006	0.006	0.008	0.000	0.003	0.001	0.000
Particulate loading, GR/ACF	0.000	0.000	0.003	0.003	0.004	0.000	0.002	0.000	0.000
Particulate emissions, lb/hr	0.0	0.0	0.2	0.2	0.3	0.0	0.1	0.0	0.0
HCl loading, mg/NCM	0.3	0.2	14.2	13.7	17.8	0.0	7.0	1.3	0.8

Table 6.9 Organic Emissions for HGD

	Background	Background	Background	Heat-up	Heat-up	24 Hr Soak	24 Hr Soak	Cool Down	Cool Down	Cool Down
Run No.	1	2	3	4	5	6	7	8	9	10
Test Date	2/25	2/25	2/25	3/4	3/4	3/4	3/17	3/17	3/19	3/19
Volume of gas samples, DSCF	37.5	35.3	39.5	46.7	46.8	47	30.1	31.5	33.8	32.9
Moisture fraction volume, percent	1.1	2.6	2.5	3.1	3.5	3.1	3.2	3.1	3.3	2.9
Average stack temperature, F	382	403	399	416	425	415	389	393	461	453
Stack volumetric flow rate, DSCFM	5508	5358	5571	4298	4237	4511	4395	4364	4782	4872
Stack volumetric flow rate, ACFM	10,316	10,448	10,807	8,541	8,709	8,982	8,568	8,533	10,143	10,202
Isokinetic rate, percent	102.3	103.3	106.7	101.1	104.2	98.2	103	101	98.9	101.5
Organic Mass, Imp. Catch, mg	3.76	3.88	3.48	4.24	2.28	2.72	3.4	1.78	3.76	3.3
Summa Can, $\mu g \times 10^{-10}$ carbon	3.2	13.0	4.6	2.8	2.0	ND	3.2	1.3	5.5	ND
Organics mg/NCM (Imp. catch)	3.55	3.88	3.11	3.21	1.73	2.05	4.0	2.0	3.96	3.55

Continuous Emission Monitoring (CEM) Results

The amount of emissions monitoring data taken during the field demonstration is voluminous. Consequently, the raw data cannot be presented in this report and graphical summaries of monitoring results are included instead. The raw data is available on electronic media for review.

The results of the CEM are shown in Figures 6.2 through 6.7. The SO_2 emissions from the startup through completion are presented in Figure 6.2. The highest SO_2 readings occurred 2 to 3 days after heat was introduced to the pit. Readings dropped to zero before the cooldown period started on March 18. Some large drops in SO_2 readings noted on Figure 6.2 are from CEM system leaks, or from switching from the process sampling point to the stack sampling point, which dropped the reading by a factor of about 4. The SO_2 emissions provided a good indication of the quantity of mustard and by-products destroyed by the HGDS. At a flow rate of approximately 500 scfm from the fume burner and a SO_2 concentration of 200 ppm at the stack, this amounts to 1 pound per hour of SO_2 at the stack. This is equivalent to 2.6 pounds of HD destroyed per hour by the HGDS.

The NO_x emissions during the field demonstration are shown in Figure 6.3. The readings were relatively constant ranging from 50 to 60 ppm. The NO_x emissions are generated from the high temperatures in the main and fume burners. System changes had little effect on overall NO_x emissions.

Figure 6.4 shows the hydrocarbon (HC) emissions from the pit to the fume burner, from a probe located at the inlet to the fume burner. The HC curve is similar to the SO_2 curve in that the HC emissions peaked about two days after heat-up. After startup, the reading dropped slowly to the 15th day, when the probe plugged and readings dropped to zero. The high peak on the 18th day is from cleaning the plug with acetone. The readings continued at zero during cooldown.

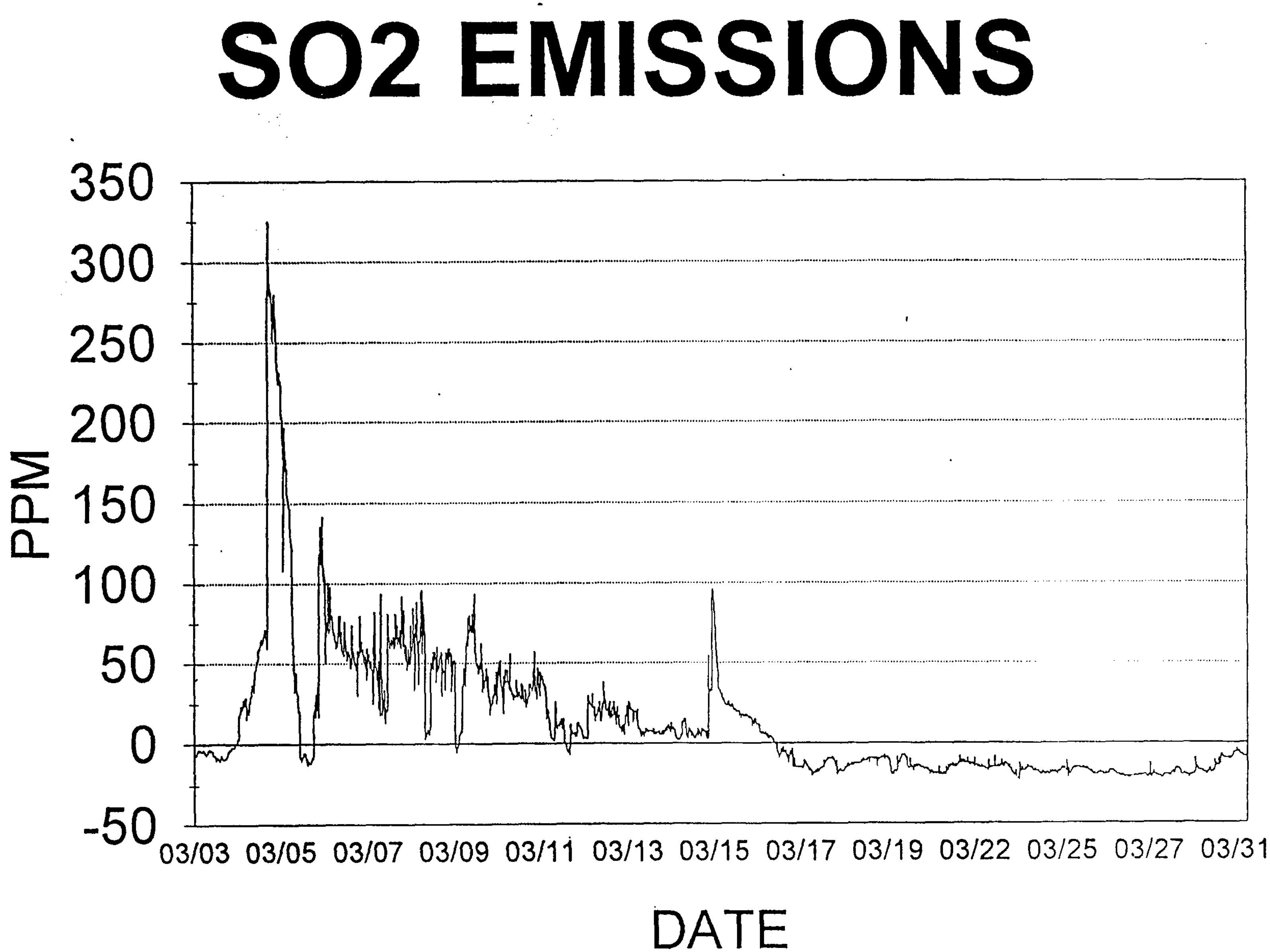


FIGURE 6.2 SO_2 EMISSIONS FROM START OF HEAT-UP THROUGH COOLDOWN OF THE FIELD DEMONSTRATION.

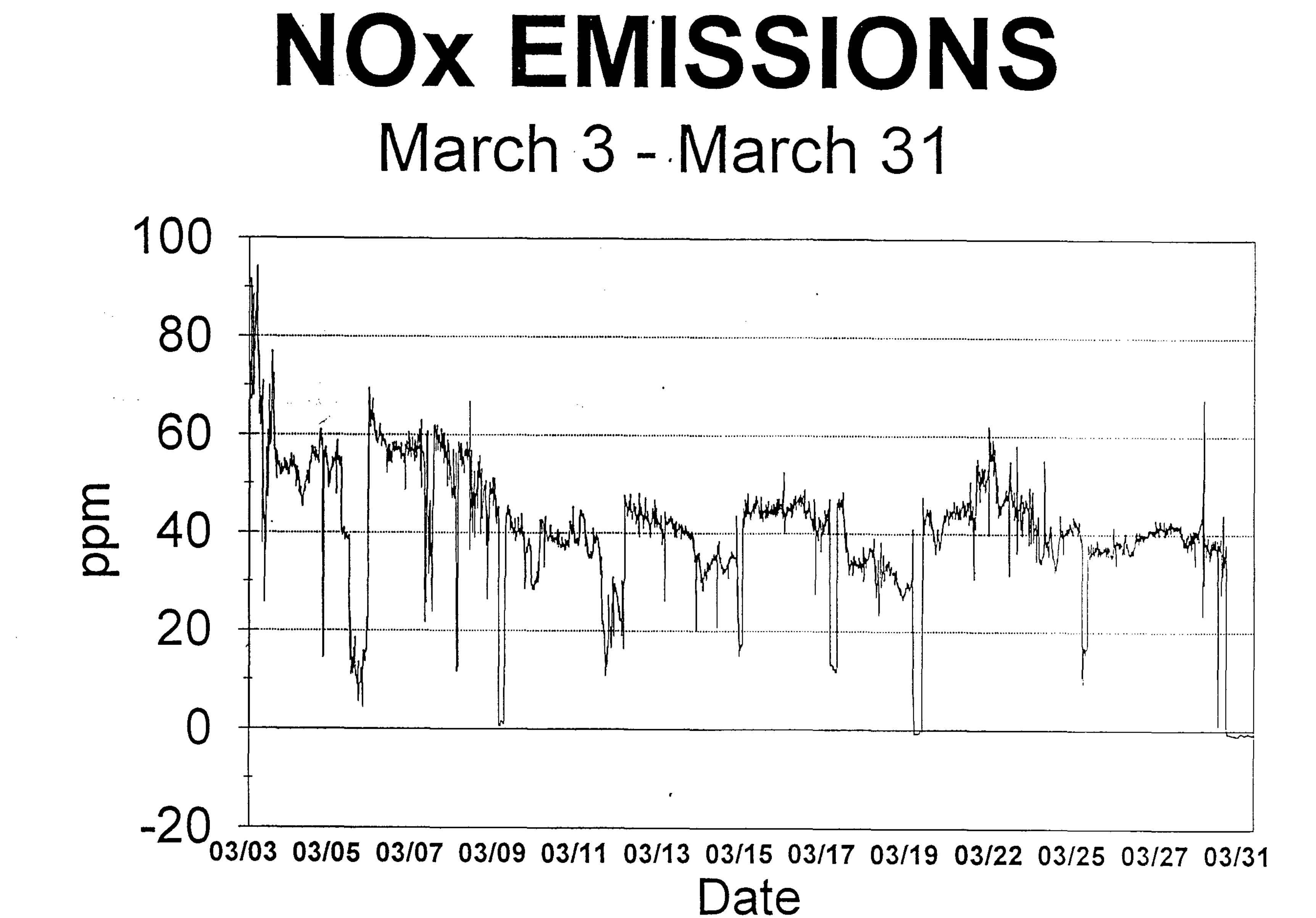


FIGURE 6.3 NO_X EMISSIONS FROM START OF HEAT-UP THROUGH COOLDOWN OF THE FIELD DEMONSTRATION.

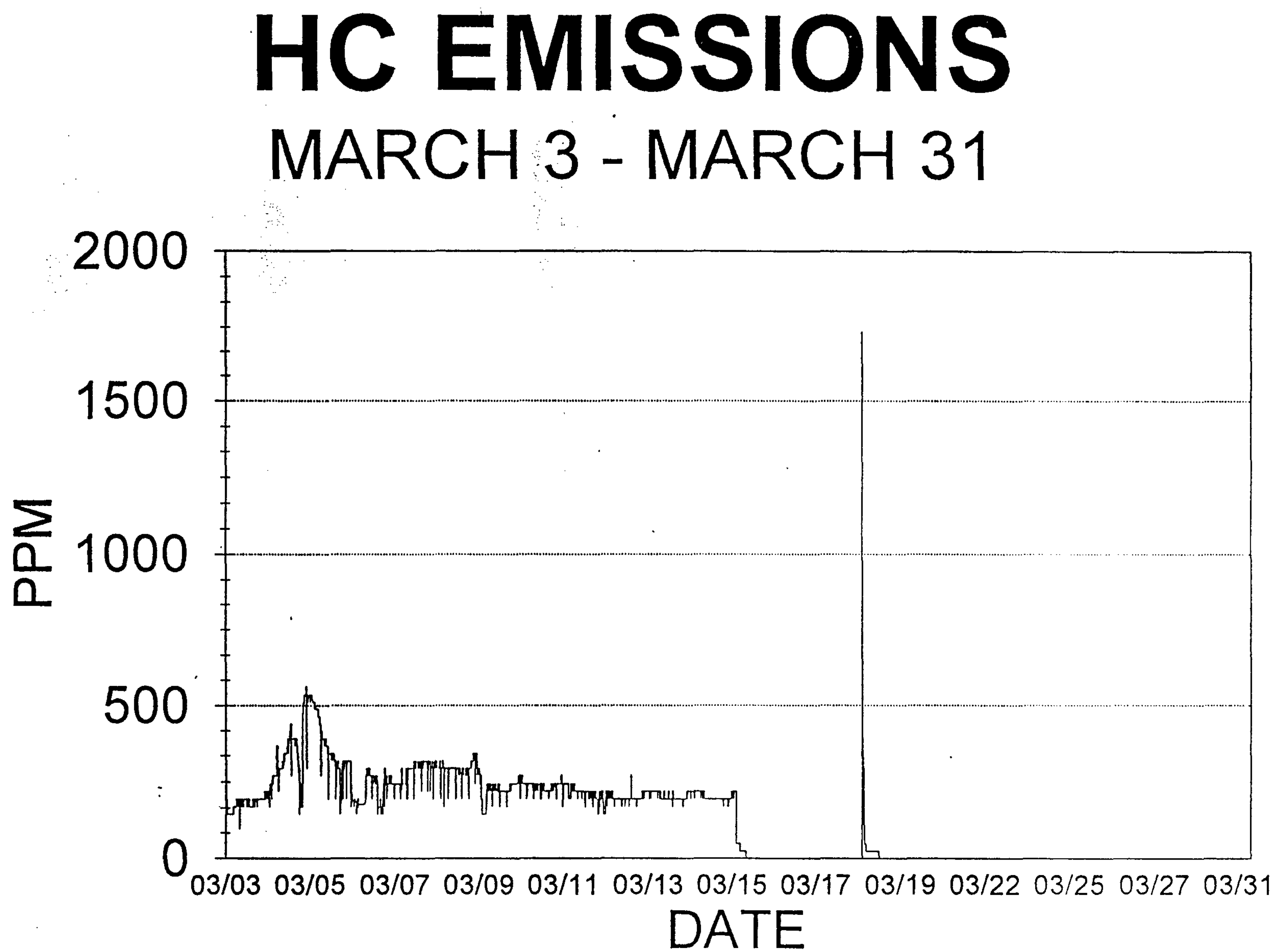


FIGURE 6.4 HC EMISSIONS FROM START OF HEAT-UP THROUGH COOLDOWN OF THE FIELD DEMONSTRATION.

The HC monitor was a safety device to monitor the process so that hydrocarbons in the burner exhaust did not reach a lower explosion limit in the pit during heatup. The lower explosion limit for methane (3.4 percent) is well above the 10,000 ppm (1 percent) operating range of the HC monitor. The HC levels did not approach 25 percent of the lower explosion limit.

The carbon monoxide (CO) readings during the field demonstration are presented in Figure 6.5, and were usually below 10 ppm. There was a large peak late on the 8th day due to a leak in the water cooled probe. It was discovered that water with ethylene glycol was leaking from the probe into the sampling system. The low CO readings indicate good combustion in the fume burner.

Figure 6.6 shows the carbon dioxide (CO_2) readings during the field demonstration, which were normally around 4 to 5 percent. Drops in the readings noted on Figure 6.6 were from sampling line leaks and switching of sampling points.

The oxygen (O_2) readings during the field demonstration are presented in Figure 6.7. The O_2 readings were approximately 13 percent at the exit of the fume burner. Peaks approaching 21 percent occurred due to sampling line leaks or cleaning of the cold traps used to remove water from the sampling lines. Other peaks are due to switching the sampling location.

A solid material accumulated in the sampling probes at the fume burner inlet and outlet. The material was a hard red substance that plugged the inlets to the sampling lines. The material also collected in the heated filters of the sampling system.

Samples of the material were collected and semi-quantitatively analyzed. There was concern that the material could contain arsenic, which is a possible indicator of the presence of Lewisite.

Solid residue from the two gas sampling probes were submitted for metals analysis by inductively coupled plasma atomic emission spectrometry (ICP-AES). A small amount of each sample (0.05 g) was weighed into a test-tube together with one mL of concentrated nitric acid. This mixture was agitated in an

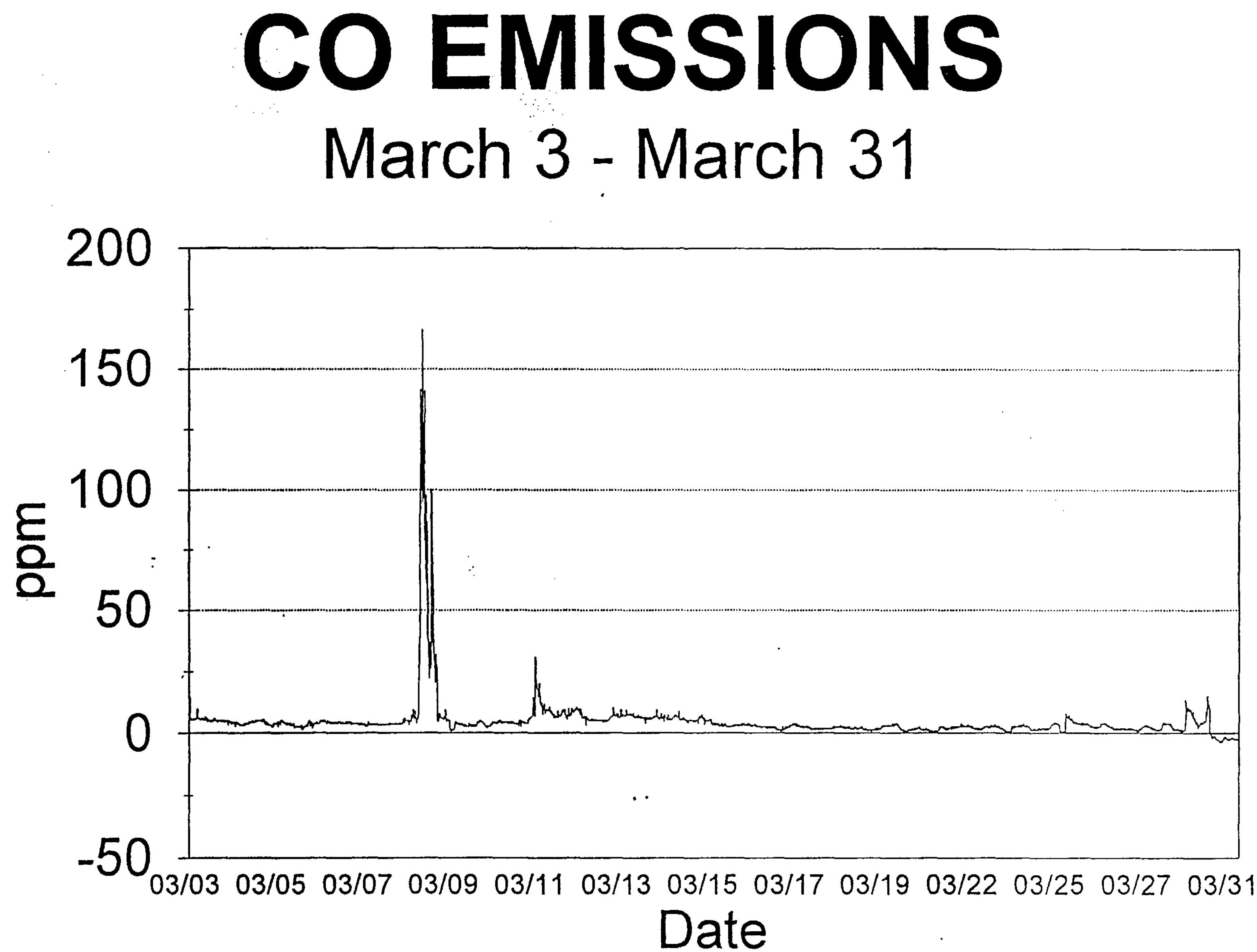


FIGURE 6.5 CO EMISSIONS FROM START OF HEAT-UP THROUGH COOLDOWN OF THE FIELD DEMONSTRATION.

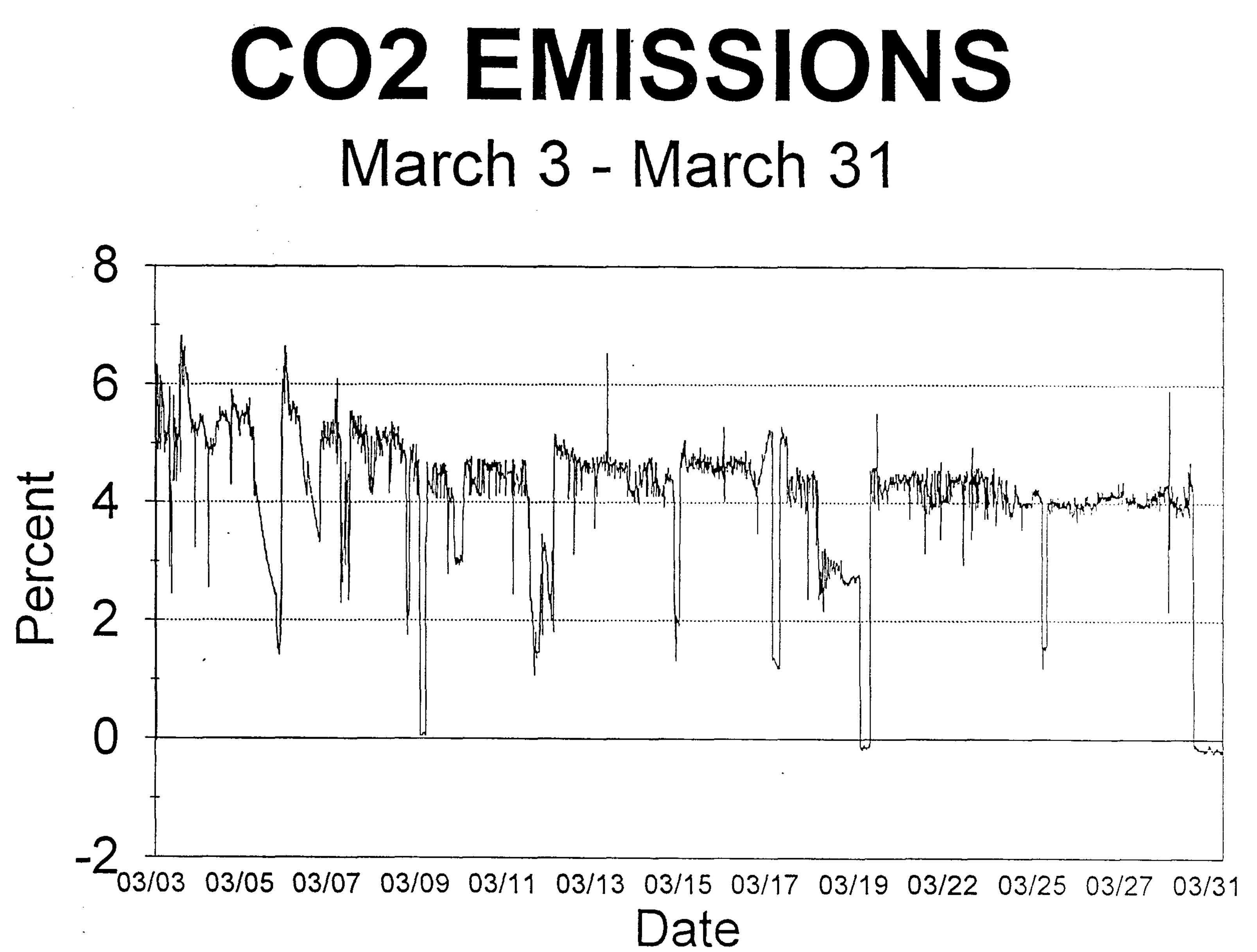


FIGURE 6.6 CO_2 EMISSIONS FROM START OF HEAT-UP THROUGH COOLDOWN OF THE FIELD DEMONSTRATION.

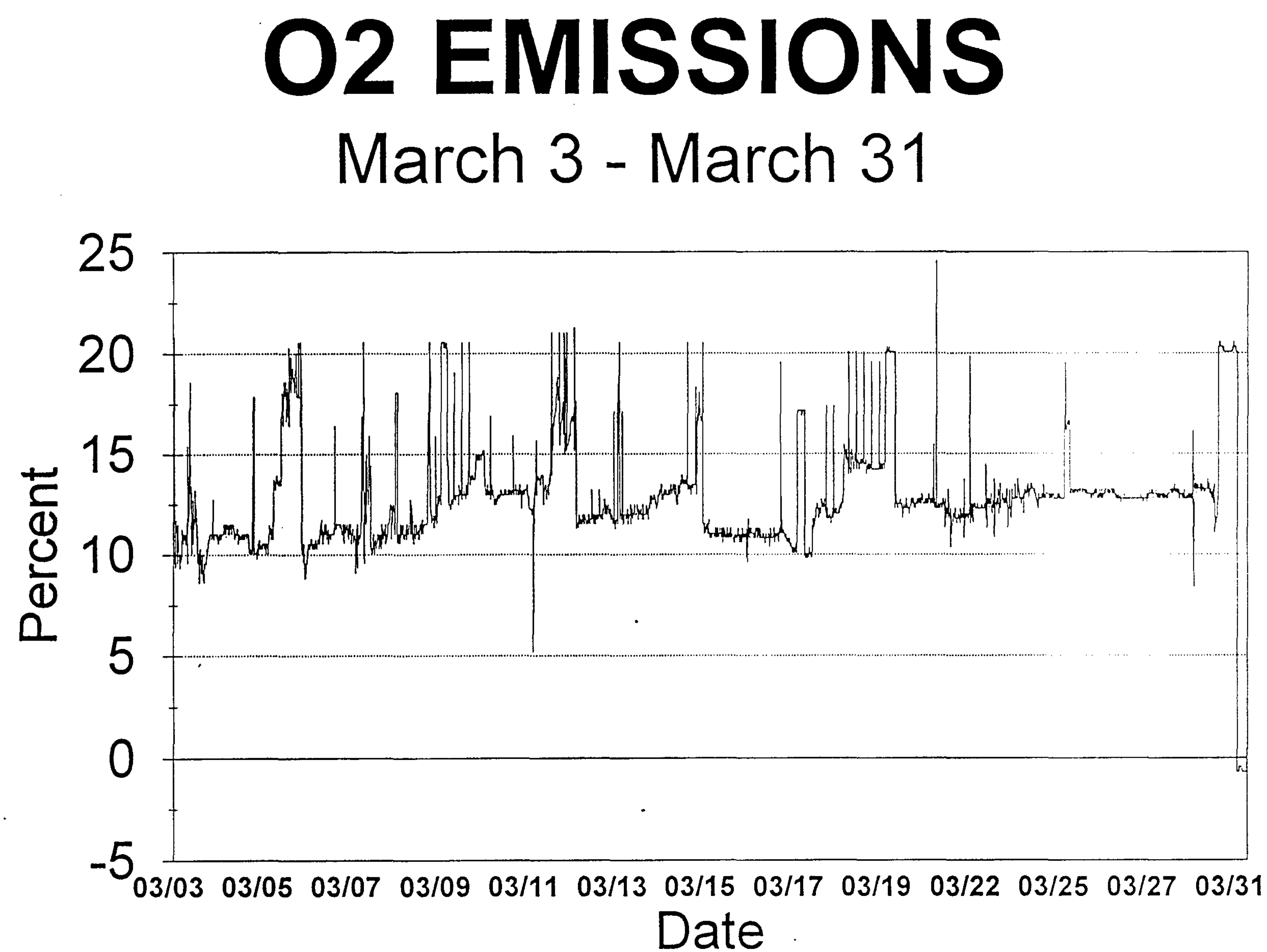


FIGURE 6.7 O_2 EMISSIONS FROM START OF HEAT-UP THROUGH COOLDOWN OF THE FIELD DEMONSTRATION.

ultrasonic bath for about 5 minutes to extract any metals soluble in nitric acid. After extraction, the sample was brought to a volume of 10 mL with the addition of distilled deionized water.

Each solution was analyzed by ICP-AES by performing a spectral scan with the simultaneous multi-channel spectrometer of each solution, to determine if metals were present. A solution of known concentration was also profiled to provide a standard for comparison. Semi-quantitative analysis was performed by comparing the net intensity for a metal in the sample with the intensity measured in the multi-element standard, and adjusted for the dilution factor from the sample extraction step.

Eight elements were determined to be present and are listed in Table 6.10.

TABLE 6.10

CONCENTRATION OF METALS IN SOLID RESIDUE FROM SAMPLING PROBE

ELEMENT	Fume Burner Inlet Sample (μg/g)	Fume Burner Outlet Sample (μg/g)
Hg	<0.5	~1
Cr	5	10
Zn	0.5	40
Pb	3	3
Ni	30	7
Mn	5	1
Fe	35	30
Cu	2	70

There was no arsenic found in the samples. The majority of the content was copper, iron, nickel, and zinc. One explanation for the material may be from the paint on the tanks and equipment in the pit. Dust generated from the pit during the demonstration was collected in the sampling system. If any moisture or other condensables collected with the dust, then the red material would build up and appear as a solid. The red material had the same color as the paint used in the pit.

6.2.2 Minicams Results

The raw data generated by the six on-line Minicams during the field demonstration was quite extensive. The data includes challenge and calibration data along with the process stream readings. There were some Minicams readings on the inlet to the fume burner that indicated the presence of HD. When HD was detected DAAMS samples were taken for verification. No detectable levels of HD contamination were noted in any DAAMS tube sample. The Station 4 Minicam at the inlet to the fume burner, was prone to false alarm which was attributed to volatilization of long-chain hydrocarbon contamination, as verified by analysis of the DAAMS tubes. In addition the by-products of HD, dithiane and oxathiane, are detected by the Minicams GC column just before and after the HD agent window on the Minicams. When the by-products are at a high concentration, a high peak is generated and results in the tail of the peak covering the agent window (masking). This results in the Minicams generating a false positive for HD.

During the course of the field demonstration, individual Minicams periodically went into the alarm mode. Standard procedure dictated that the alarming unit be investigated to determine the cause of the alarm. When a Minicams unit went into the alarm mode the technician would inject a 1.0 TWA calibration solution directly into the sample inlet portal. This operation was performed in order to determine if the individual Minicams was still operating within the calibration range. In those instances where the instrument was not in calibration the technician re-calibrated the instrument to return the instrument to the proper calibration setting and thereby silencing the alarm. In the those instances where the instrument was determined to be within calibration tolerances, the technician would then collect a pair of DAAMS (TENEX solid sorbent) tubes for analysis in the RMA Analytical laboratory. In all instances, the collected tubes confirmed that no HD contamination (greater than 0.5 TWA-0.0015 mg/m^3) was present.

The vast majority of these alarm events were due to some type of instrument error which either self-corrected or required a slight adjustment by the operator. However, there were instances in which the Minicams alarmed and indicated greater than 1.0 TWA readings for the presence of HD. The standard procedure was for the operator to investigate the unit and to attempt to determine the source of the alarm. If the unit did not self-correct or the operator could not determine the source of the alarm, a pair of DAAMS tubes was used to collect an air sample. These tubes were analyzed at the RMA AAL by RMA personnel. In each instance, the DAAMS tubes revealed that there was no detectable HD contamination present in the sample.

6.3 PROCESS OPERATIONAL RESULTS

6.3.1 General

The field demonstration was successful in meeting its functional requirements for complete volatilization and destruction of the mustard agent in the pit, and destruction of the mustard in the pit exhaust gas. The design criteria for heat soak of concrete in the mustard pit (350 °F for 24 hours) was met. During operation, the fume burner was successfully operated within expected tolerances of the design criteria at 2,000 °F for 2 seconds, except that the residence time was not achieved over the entire operation due to false flow measurement readings (as explained later).

As with the emissions data, the process data taken during the field demonstration is too voluminous for this report. Consequently, graphic summaries of process results are presented instead of raw data. The raw data is available on electronic media for review.

The operational results are presented below using the design criteria and functional requirements as a yardstick for success. More detail regarding the operational results of process equipment operation is presented below.

6.3.2 Mustard Pit Heatup

The primary design criteria of the HGDS was to heat all areas of the mustard pit walls and floor to 350 °F for a 24-hour period. The functional requirement was to volatilize or break down all chemical agent in the concrete structure and steel tanks. There were 117 thermocouples in the pit walls and floors. The thermocouples on the outer skin of the concrete (at the soil interface) were used to determine that the temperature and time criteria were met. After a 14 day heatup period, all thermocouples reached or exceeded the temperature requirement of 350 °F on March 17, 1994, and were held above this temperature for 24 hours. The temperature profiles of the thermocouples are presented in Figure 6.8, where the thermocouples are grouped and averaged according to the following zones:

- Inner thermocouples on the inside skin of the pit walls and floor
- Middle thermocouples in the middle of the concrete in the walls and floor
- Outer thermocouples on the outside skin of the pit walls and floor at the soil interface
- Soil thermocouples in the soil outside the pit

After immediately heating up to approximately 140 °F upon startup, the inner thermocouples (average) increased at a rate of 70 °F per day until March 8. From March 8 until the start of the cooldown period on March 18, the inner thermocouples increased at a lower rate of 26 °F per day to a maximum of 710 °F.

As expected, the inside thermocouples heated up faster than the other sets, and the outer thermocouples were the last to reach temperature. As such, the outer thermocouples were of greater interest during operation, and the profile of the outer zone average is shown in Figure 6.9 in larger scale. The outer thermocouples (average) heated up at a rate of 95 °F per day on March 4 and 5. The rate slowed to 23.5 °F per day from March 6 to March 18, when a maximum of 495 °F was attained before cooldown commenced. It is noted that the average temperature of the outer thermocouples far exceeds the 350 °F minimum, because most of the outer thermocouples continued to rise well beyond the 350 °F while the final (coldest) thermocouple was still heating up.

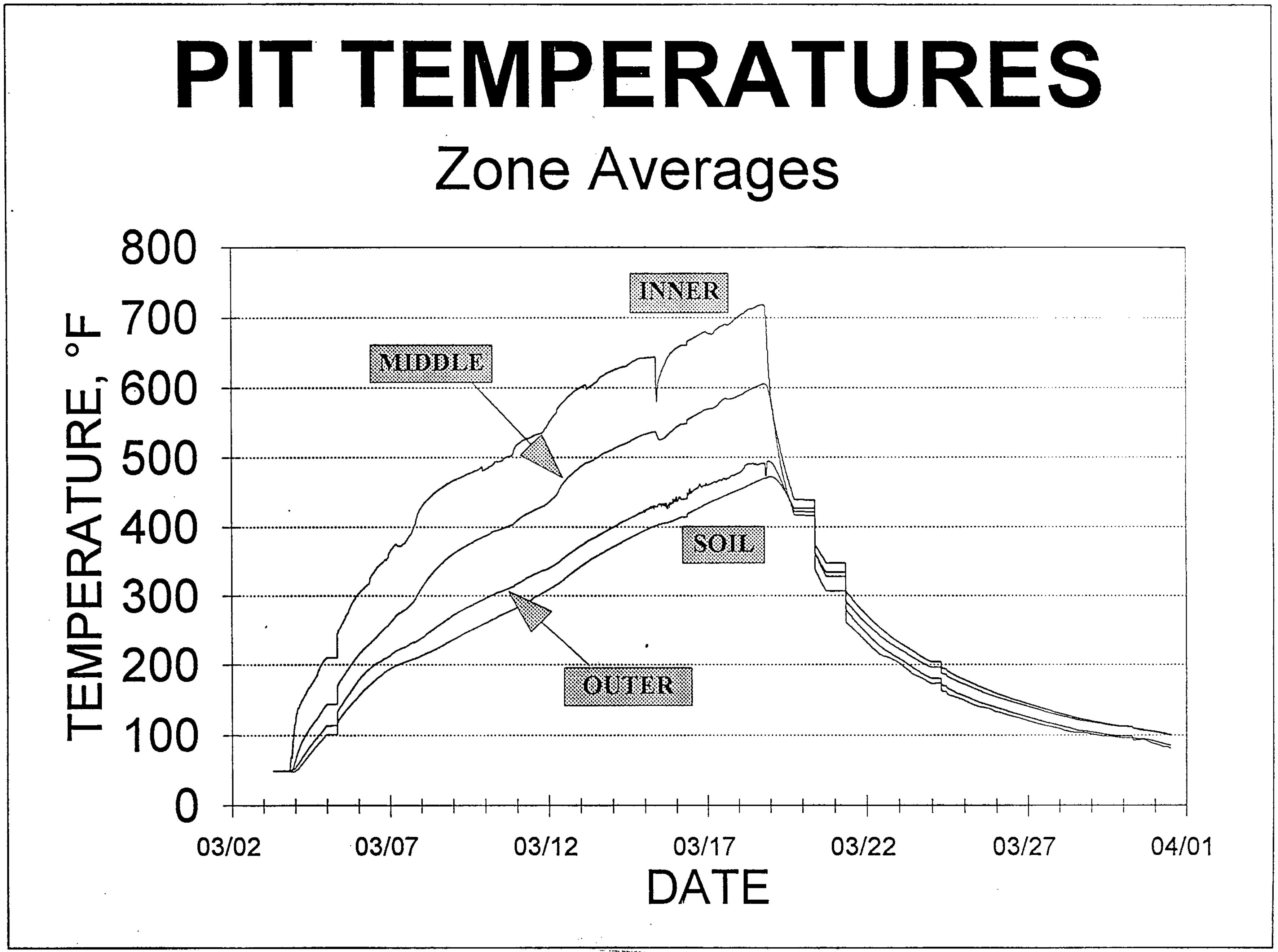

PIT TEMPERATURES
Zone Averages
TEMPERATURE, °F
800
700
600
500
400
300
200
100
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
DATE
INNER
MIDDLE
SOIL
OUTER

FIGURE 6.8

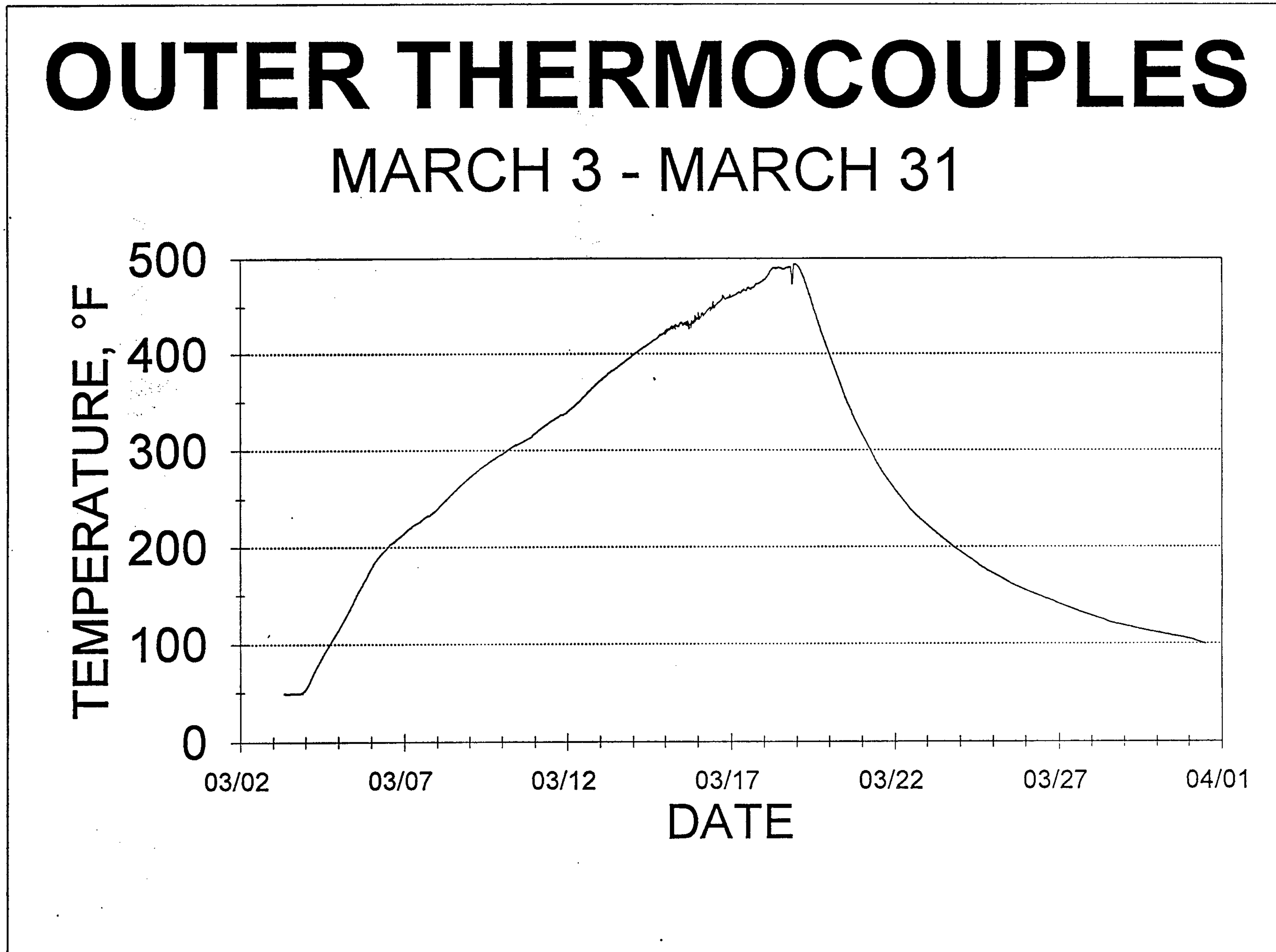

OUTER THERMOCOUPLES
MARCH 3 - MARCH 31
TEMPERATURE, °F
500
400
300
200
100
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
DATE

FIGURE 6.9

Figure 6.10 presents the temperature profiles for heatup and cooldown of two outer thermocouples which are the first (hottest) and last (coldest) outer thermocouples to reach temperature criteria. For comparison, temperature profiles of thermocouples on the inner floor and in the soil outside the pit are presented in Figure 6.11.

Pit temperature design criteria were fully met, and analytical results of the concrete core samples indicate that the functional requirement to volatilize or destroy the agent was met.

Main Burner

The main burner output was sufficient to meet the heat input objectives of the field demonstration. The heat output of the main burner during operations in terms of temperature is presented in Figure 6.12. The main burner flows during the field demonstration consisting of combustion air and natural gas are presented in Figures 6.13 and 6.14 respectively.

Recirculation System

The main burner and recirculation system were designed to deliver 10,000 pounds per hour of hot air to the pit. This is based on the mass and energy balance, which allocates the proper amount of energy delivery to the pit to achieve the required heating. Unfortunately, the flow element in the recirculating system failed, and no data was available to confirm the heat input from the recirculating system. However, since the pit heatup time of 14 days corresponds closely to the calculated heatup time of 11.5 days, the heat input from the main burner and recirculation system met the objectives of the field demonstration.

Primary Containment

The design criterion of -0.50 inches of water gauge (WG) was set to ensure that vapors from the mustard pit were pulled through the fume burner treatment system. The negative pressure over time in primary containment during the field demonstration is shown in Figure 6.15. During operation, the pressure criterion was never achieved, but the data shows that the operating

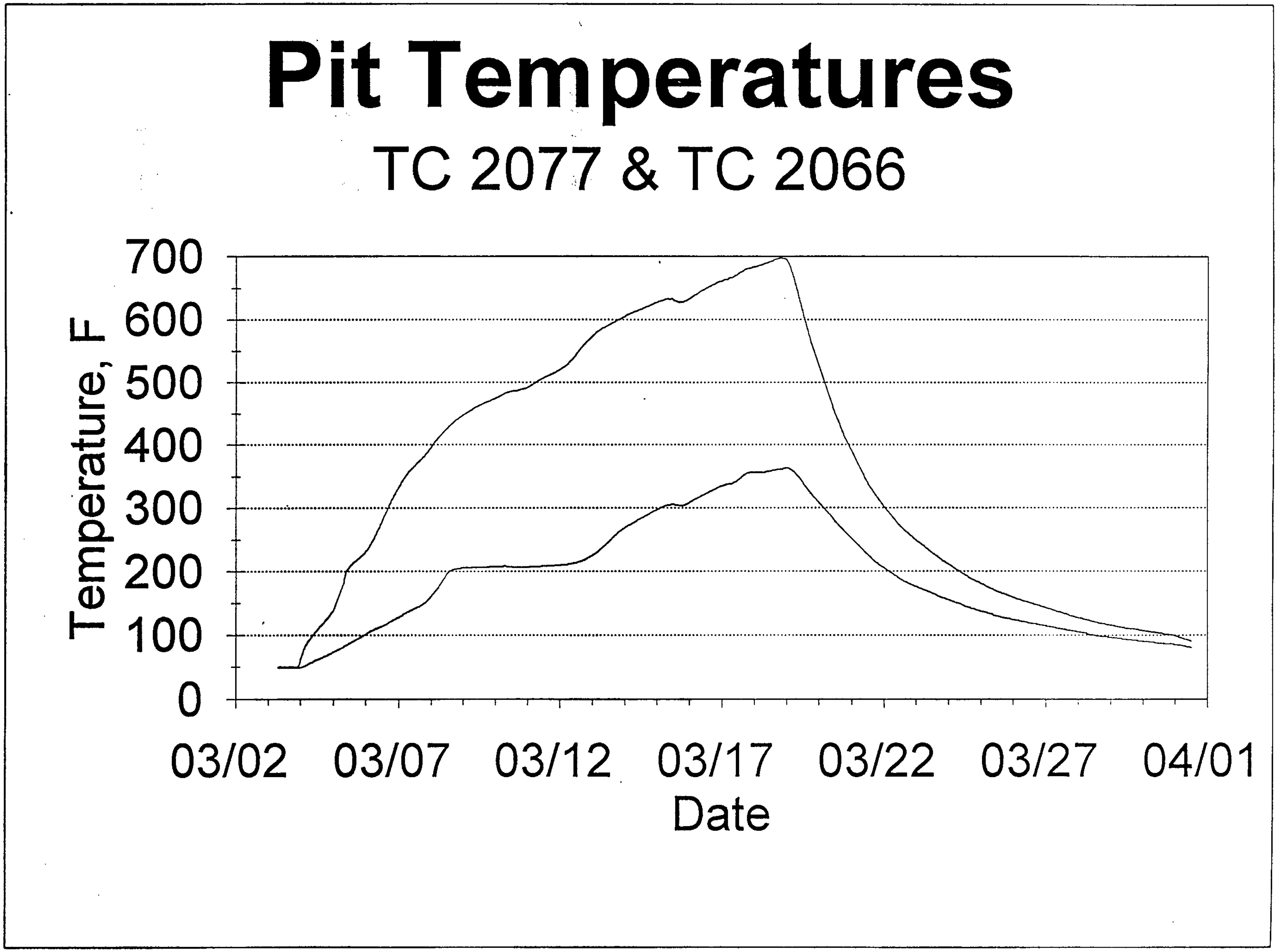

Pit Temperatures
TC 2077 & TC 2066
Temperature, F
700
600
500
400
300
200
100
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.10

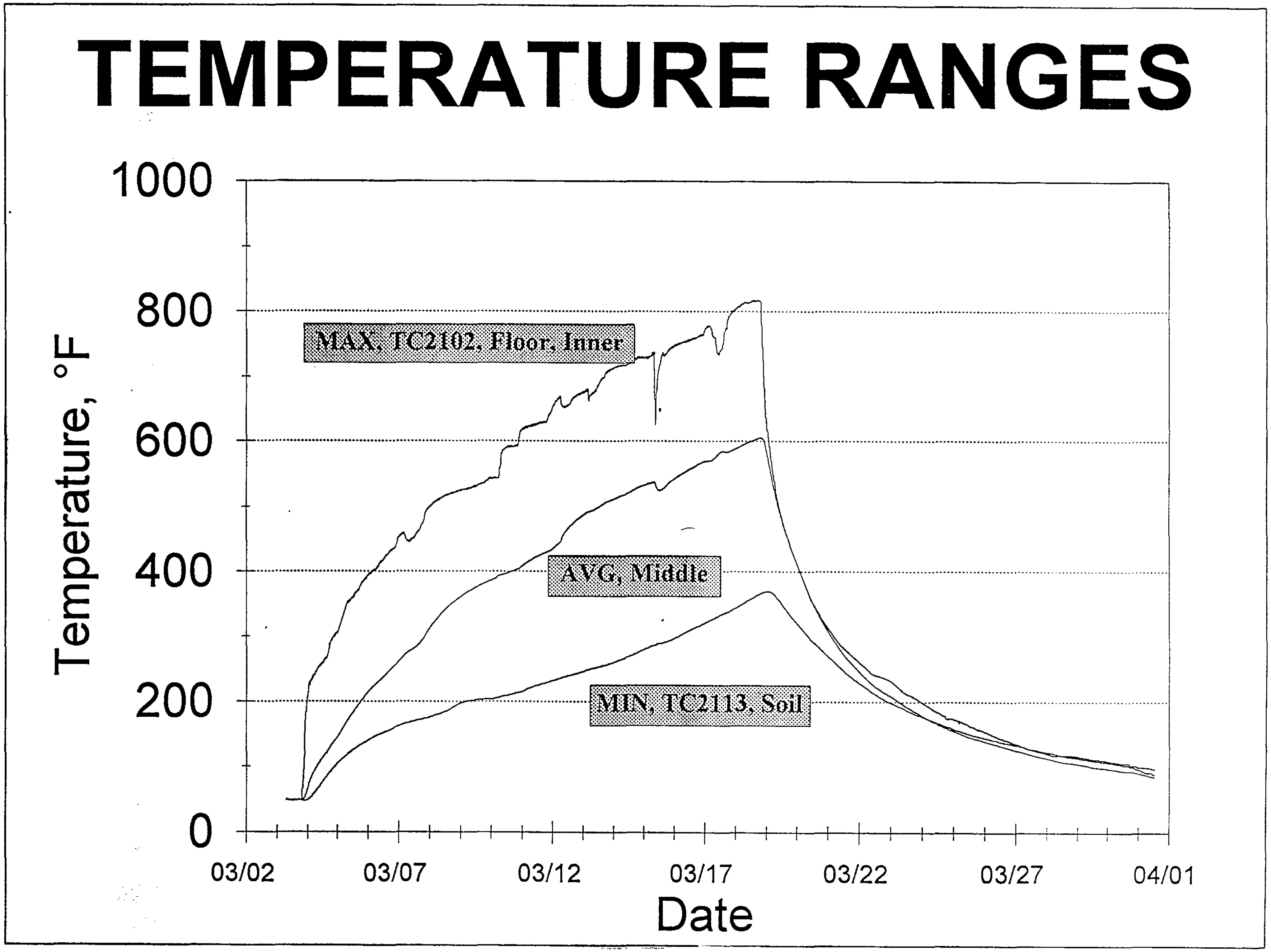

TEMPERATURE RANGES
Temperature, °F
1000
800
600
400
200
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date
MAX, TC2102, Floor, Inner
AVG, Middle
MIN, TC2113, Soil

FIGURE 6.11

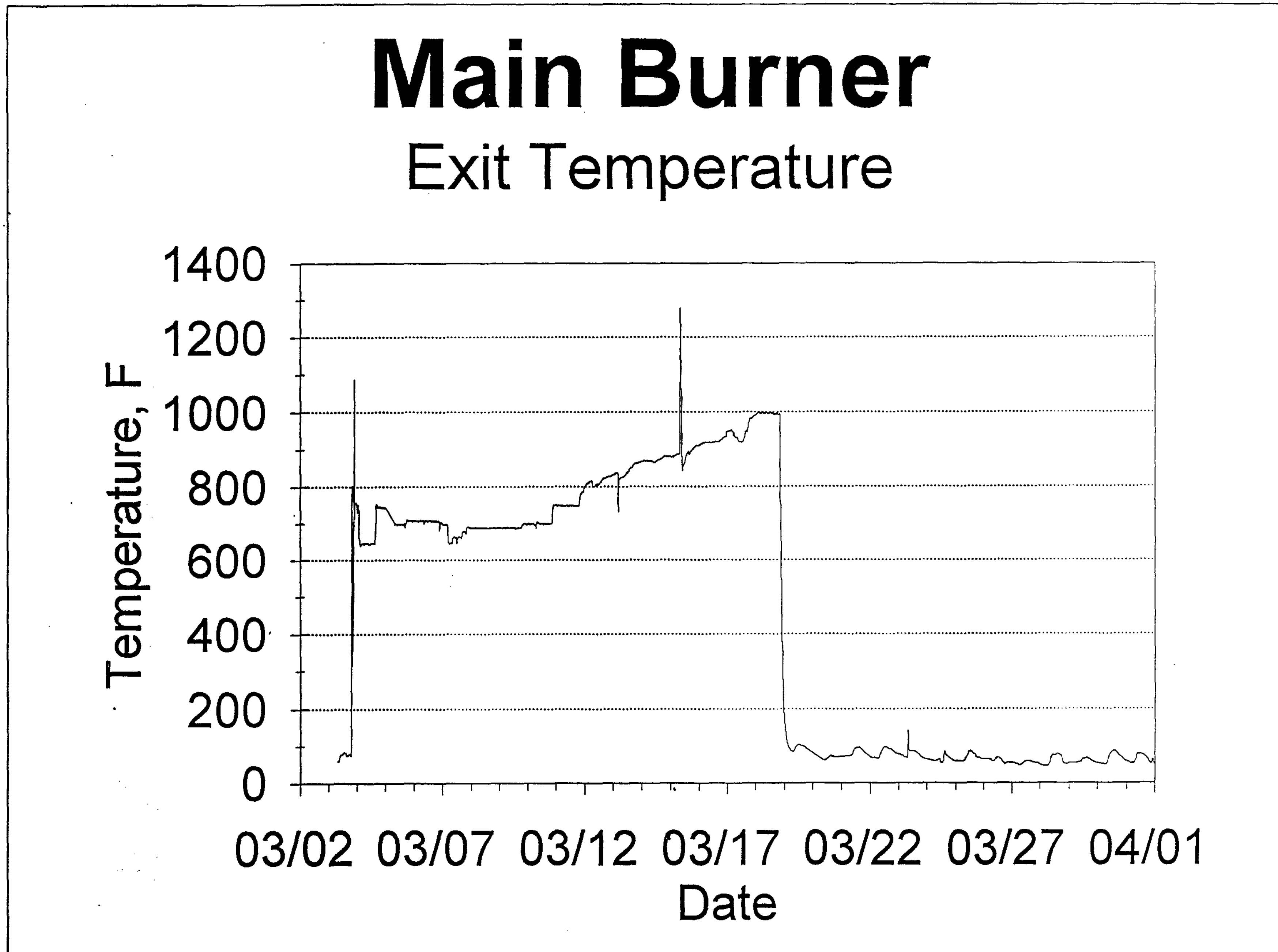

Main Burner
Exit Temperature
Temperature, F
1400
1200
1000
800
600
400
200
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.12

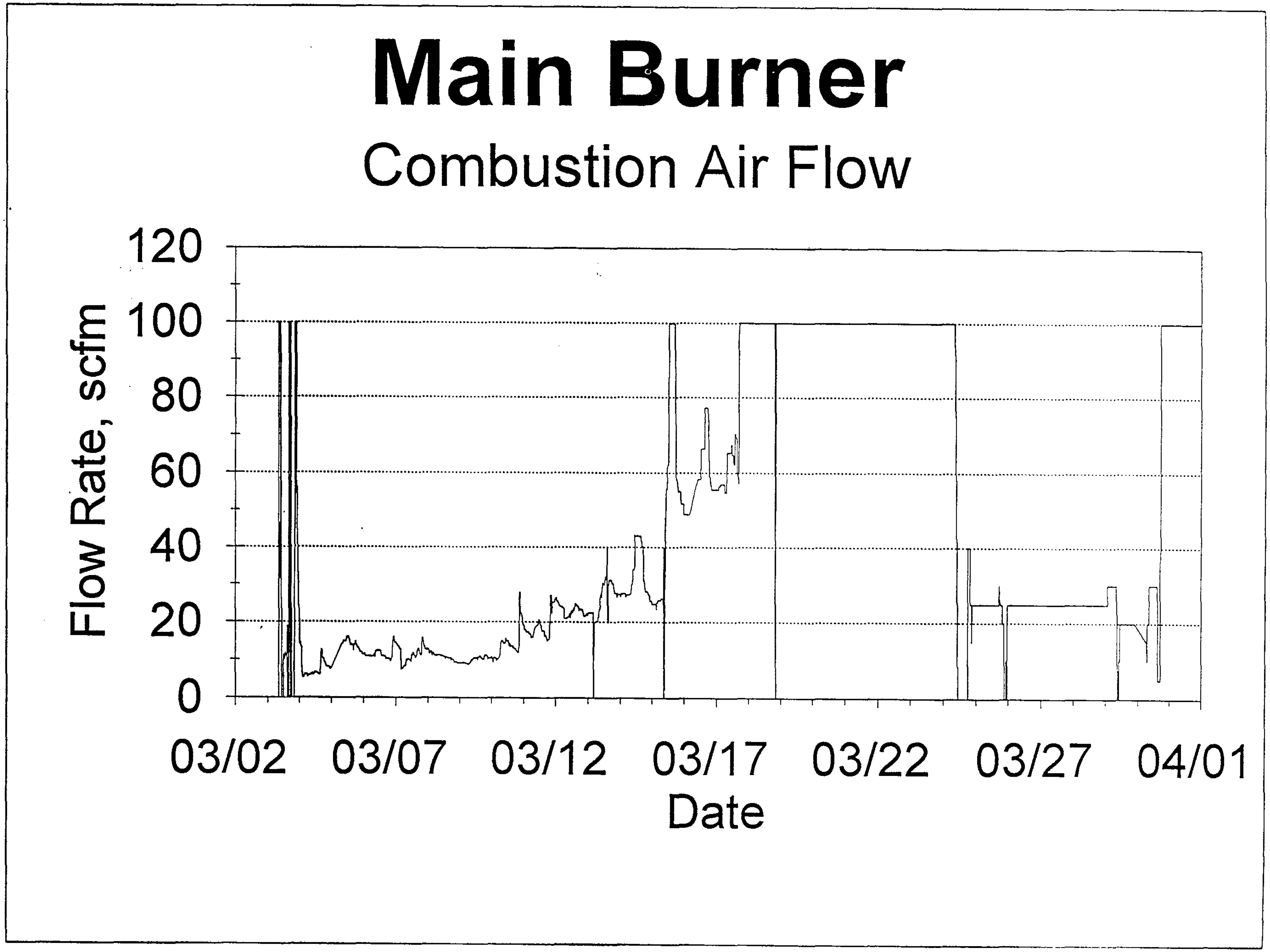
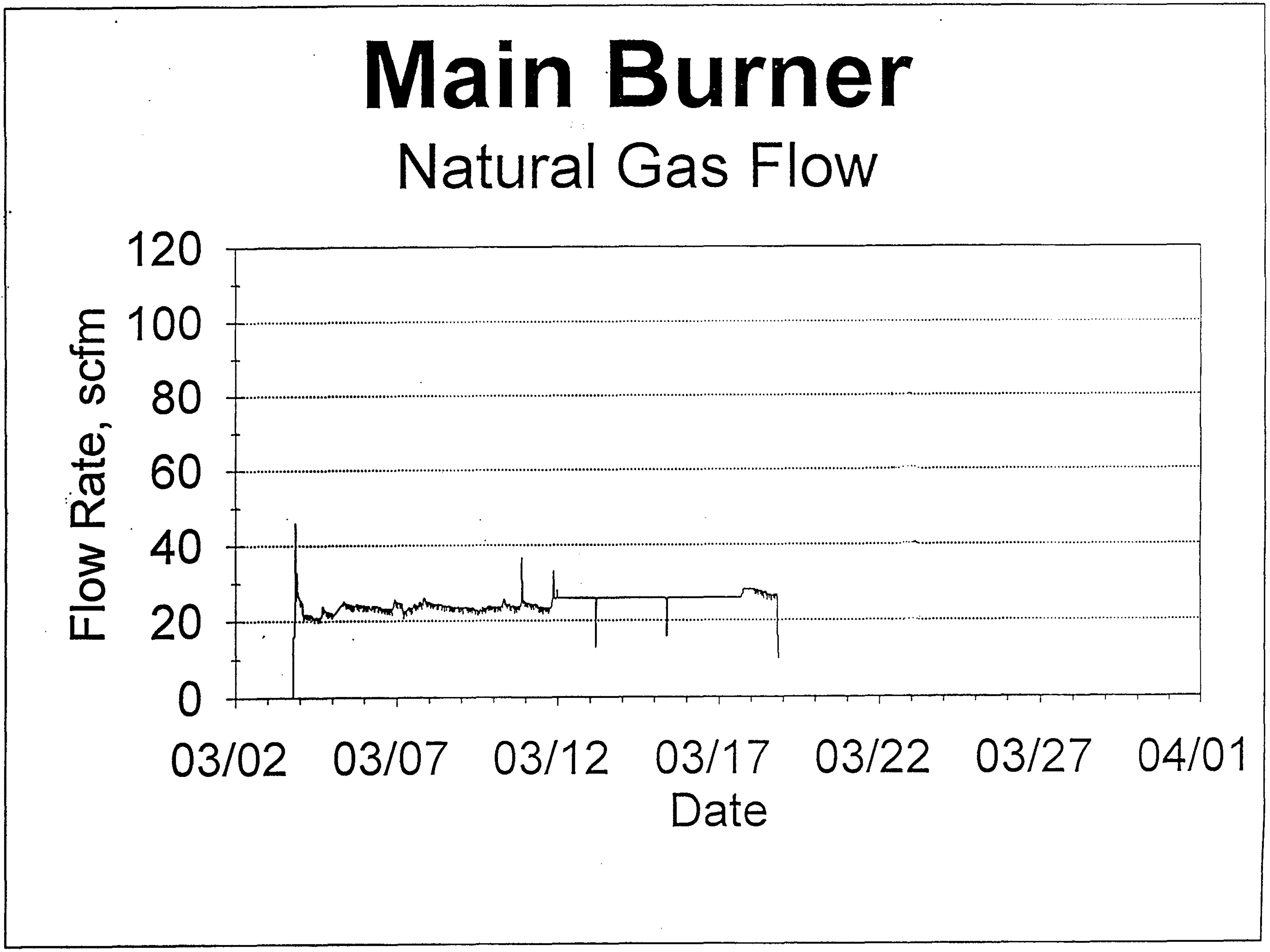
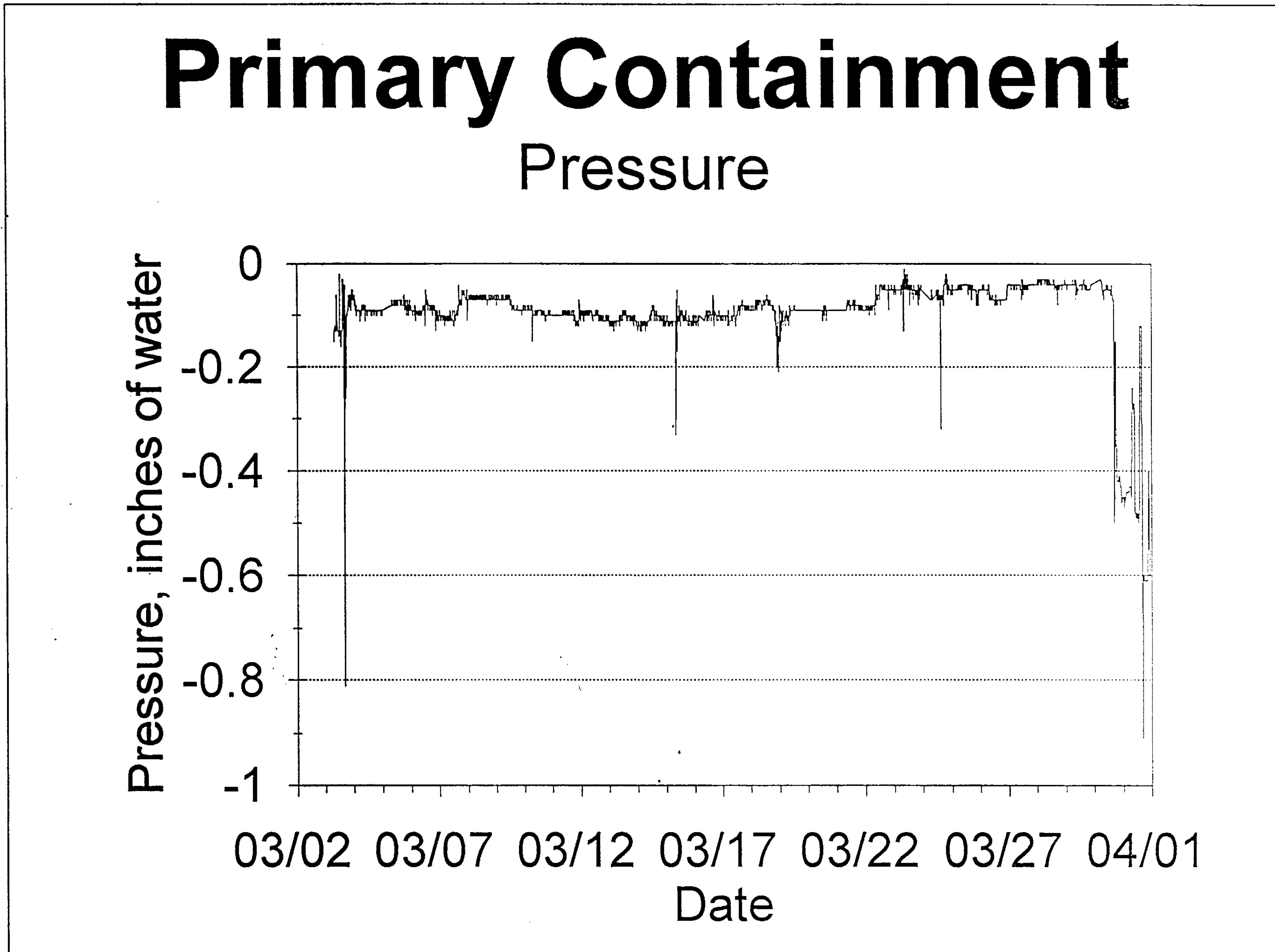

Main Burner
Combustion Air Flow
Flow Rate, scfm
120
100
80
60
40
20
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.13



Main Burner
Natural Gas Flow
Flow Rate, scfm
120
100
80
60
40
20
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.14



Primary Containment
Pressure
0
-0.2
-0.4
-0.6
-0.8
-1
Pressure, inches of water
03/02 03/07 03/12 03/17 03/22 03/27 04/01
Date

FIGURE 6.15

pressure was always negative, and more negative than the secondary containment. Consequently, any flow of leakage was inward from the secondary containment to the primary containment. The functional requirement for negative pressure in primary containment was met, since the primary containment was always more negative than secondary, and flow from the primary containment was successfully delivered to the fume burner.

The temperature profile inside primary containment for the field demonstration is presented in Figure 6.16. The maximum temperature inside the primary containment was approximately 750 °F, as expected. The three tanks inside the pit were subjected to this temperature during the field demonstration, and far exceeded the minimum heat soak requirement of 350 °F for 24 hours.

The structural performance of the primary containment structure under the pressure and temperature conditions of the field demonstration appeared satisfactory and no damage was noted.

Fume Burner

The primary criteria for operation of the fume burner was to maintain a temperature of 2,000 °F ± 200 °F at a residence time of 2 seconds in the fume burner chamber. The functional requirement of the fume burner was to completely destroy all mustard agent in the process exhaust gas.

The fume burner was operated within the pre-set tolerances (± 200 °F) of the design temperature of 2,000 °F for the duration of the field demonstration, and was consistently operated at a temperature near 1,900 °F. A profile of the fume burner temperature during the field demonstration is presented in Figure 6.17.

It should be noted that the continuous flow element at the fume burner inlet had previously been damaged during installation. The unit was repaired and re-calibrated at the factory, and re-installed in the ductwork on March 9, six days after startup. In the interim period, a pitot tube was installed in the fume burner inlet to measure flows.

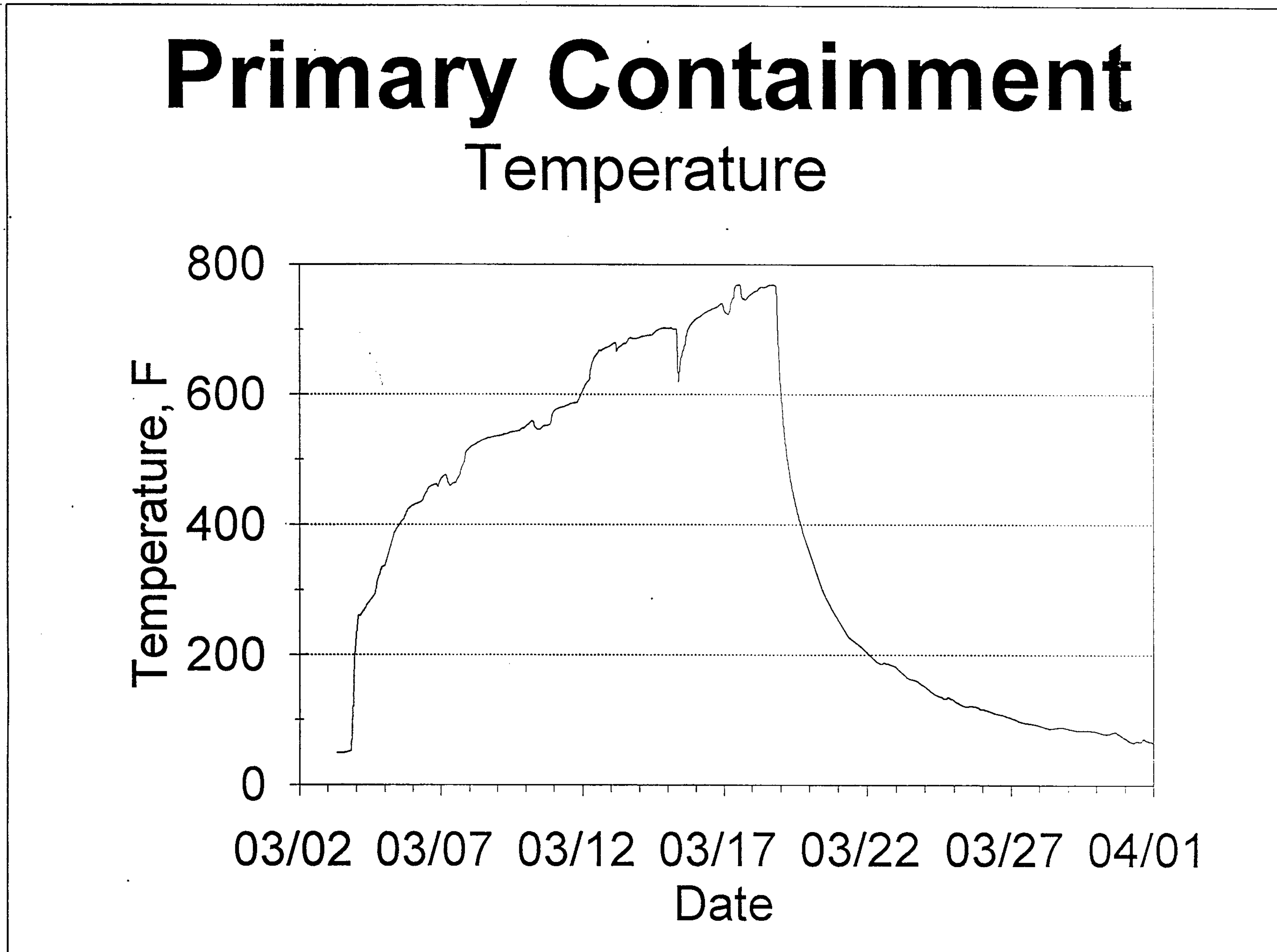

Primary Containment
Temperature
Temperature, F
800
600
400
200
0
03/02 03/07 03/12 03/17 03/22 03/27 04/01
Date

FIGURE 6.16

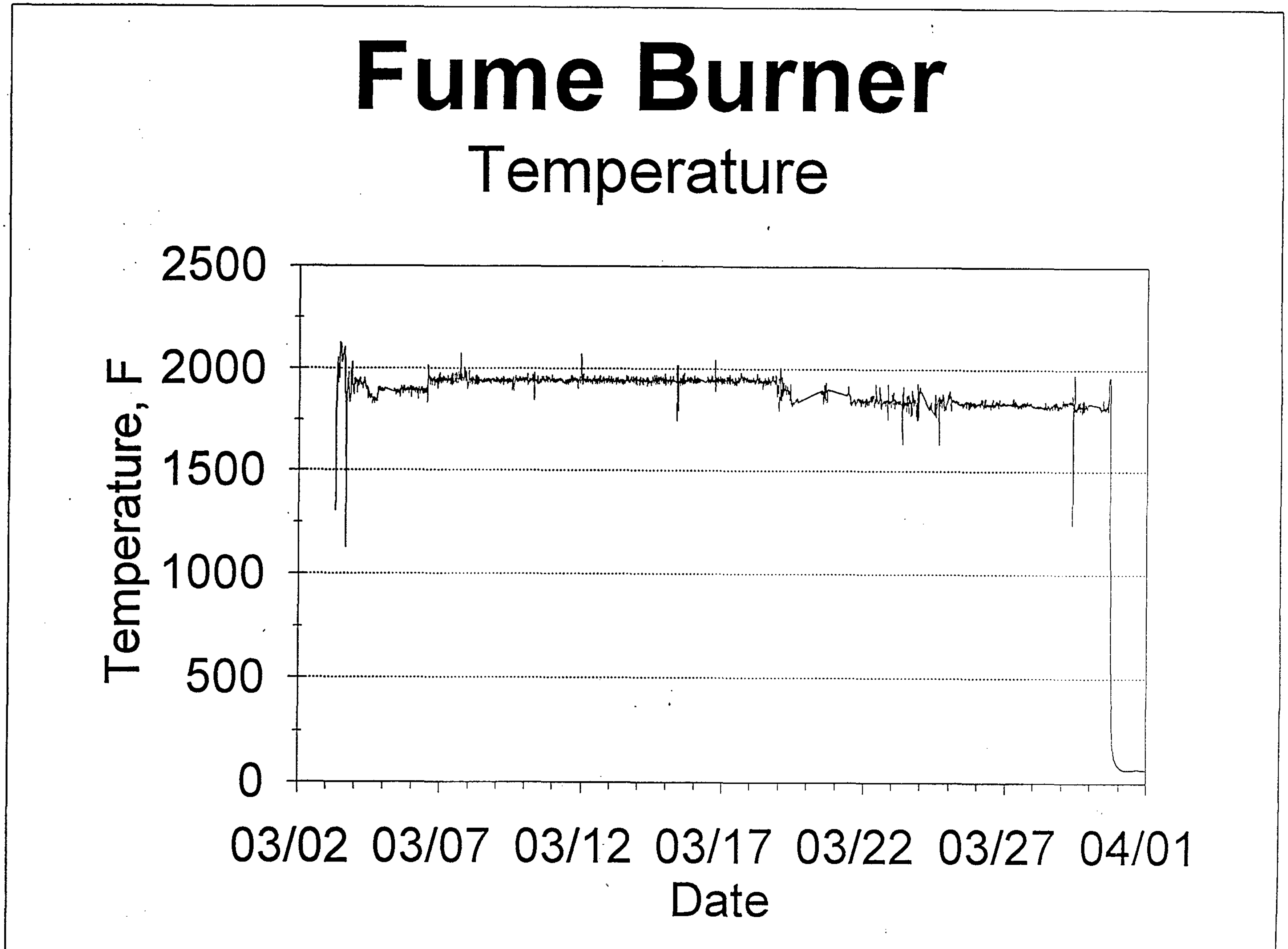

Fume Burner
Temperature
Temperature, F
2500
2000
1500
1000
500
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.17

March 9 is a key date for operation of the fume burner system, because the pitot tube readings were correct before March 9, while the continuous flow readings read erroneously low after March 9. At the time, the continuous flow element readings were not questioned because the pitot tube was thought to have experienced plugging problems. The false readings affect all areas of fume burner performance, and many areas of system performance. The false flow readings led operators to believe that the system was operated in the range of 1.6 seconds to 3 seconds residence time. The system actually was operated at a lower residence time.

A graph of the actual residence time for the process gas in the fume burner chamber is presented in Figure 6.18. The actual residence times during the field demonstration varied between 0.75 and 2.5 seconds. The fume burner results have been examined during two operating periods, prior to March 9 (pitot tube readings) and after March 9 (continuous flow element readings). Based on the pitot tube readings (before March 9), the fume burner was operated at a residence time between 1.5 and 2.5 seconds. During this time, the fume burner demonstrated the capability of meeting the residence time criterion during operation. From agent monitors in the stack, mustard agent in the exhaust gas which passed through the fume burner was destroyed, indicating that the fume burner successfully met its performance objectives while operating within an acceptable range for residence time and temperature.

The residence times after March 9 were typically near 1.5 seconds and varied between 0.75 and 2 seconds. These were generally lower than the 2 second criteria for residence time, and not identified as such until after the field demonstration was complete. During cooldown, flows were increased through the pit to promote cooling, with the side effect of lower residence time in the fume burner.

The flows entering the fume burner include combustion air, natural gas, and the pit exhaust. The instrument data for these flow inputs are presented in Figure 6.19. The instrument data shown in Figure 6.19 for pit exhaust flow was later found to be incorrect. After completion of the HGDS, an examination of the flow rate data indicated problems with the accuracy of the flow measurement device. The continuous flow measurement device on the inlet to the fume burner shows rates near the design rates from the mass balance.

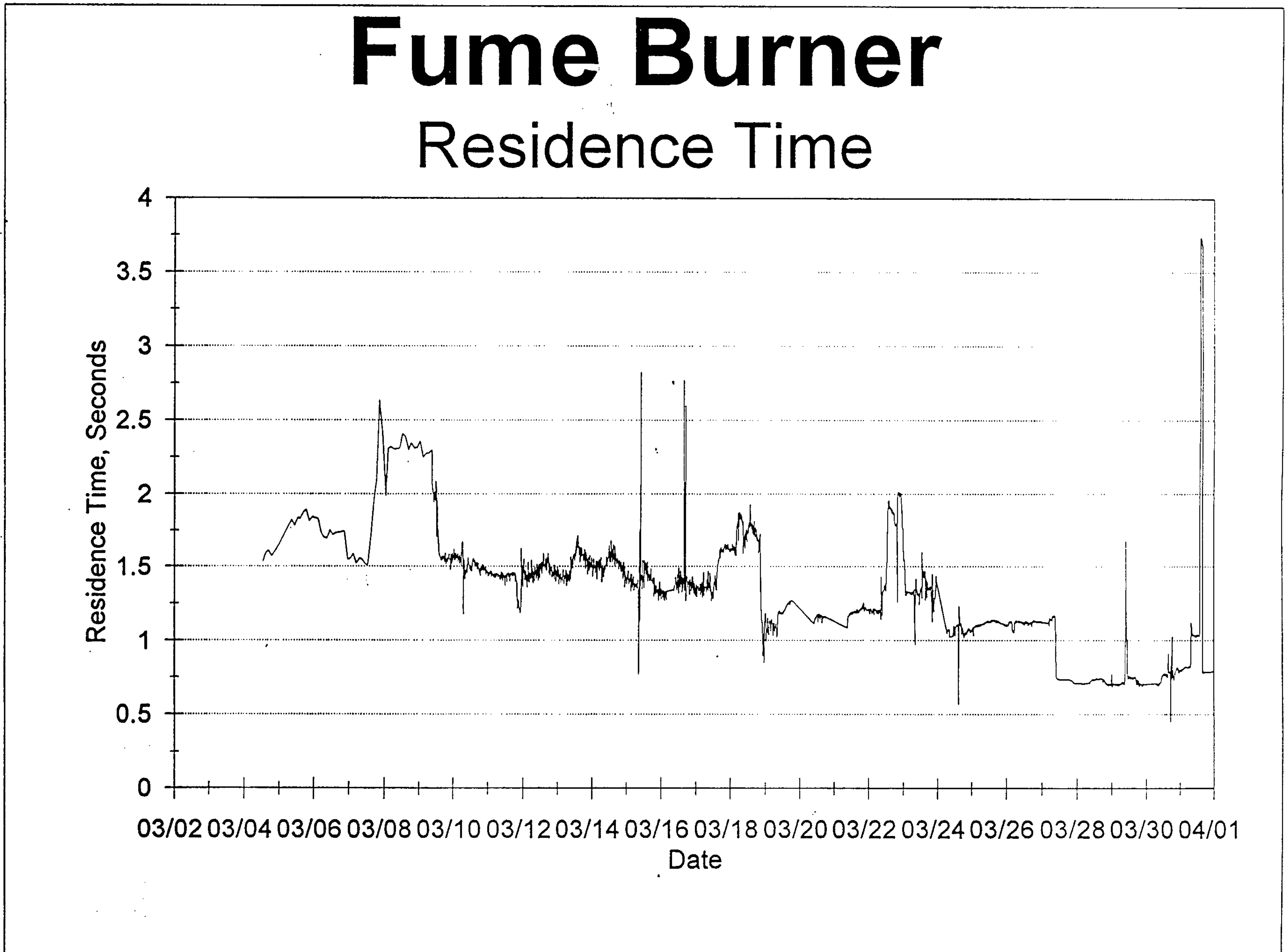

Fume Burner
Residence Time
Residence Time, Seconds
4
3.5
3
2.5
2
1.5
1
0.5
0
03/02 03/04 03/06 03/08 03/10 03/12 03/14 03/16 03/18 03/20 03/22 03/24 03/26 03/28 03/30 04/01
Date

FIGURE 6.18

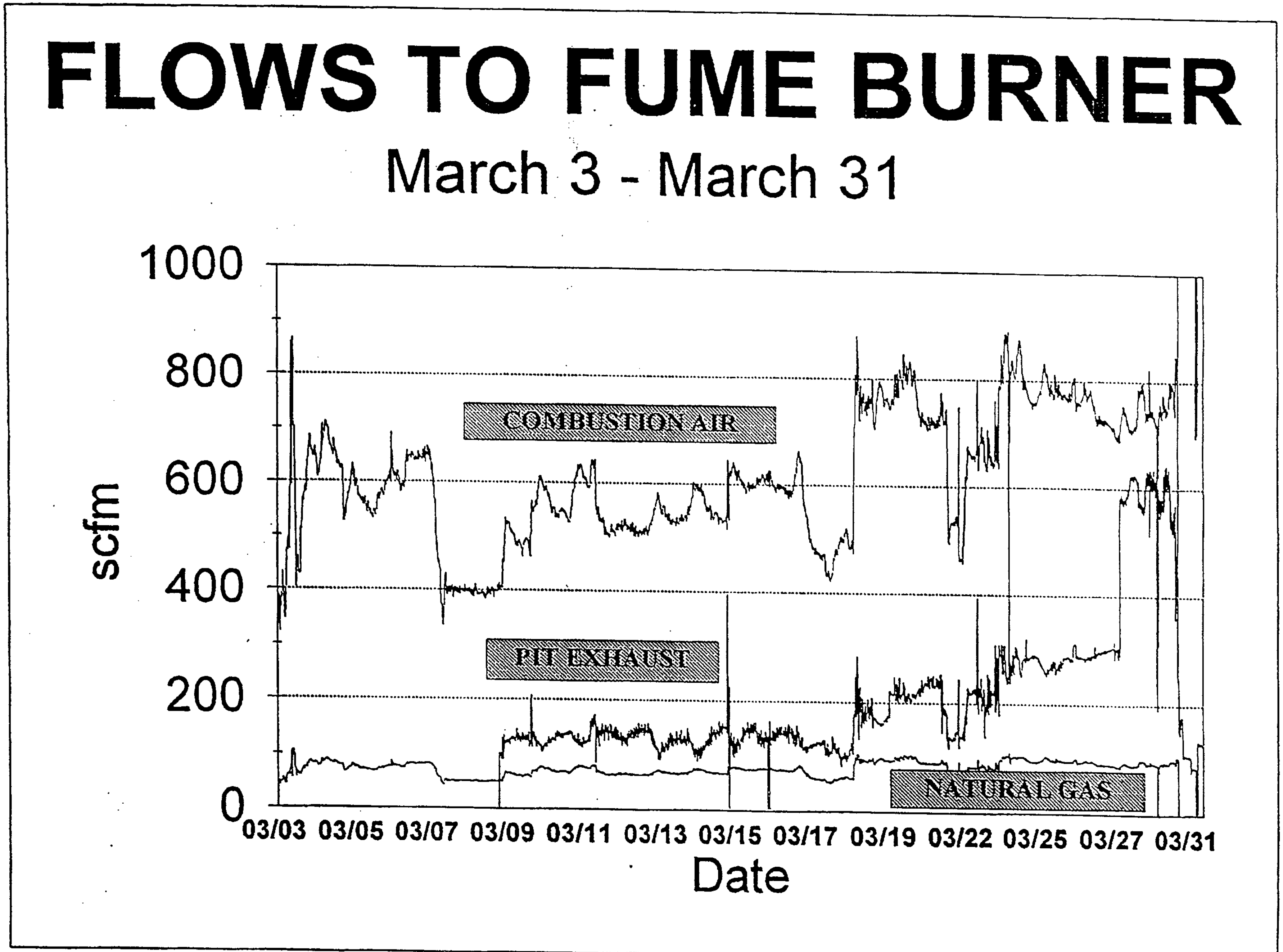

FLOWS TO FUME BURNER
March 3 - March 31
1000
800
600
400
200
0
scfm
COMBUSTION AIR
PIT EXHAUST
NATURAL GAS
03/03 03/05 03/07 03/09 03/11 03/13 03/15 03/17 03/19 03/22 03/25 03/27 03/31
Date

FIGURE 6.19

However, the flow of natural gas which is required to heat the process gas to 2,000 °F and the flow to the stack were much higher than expected. A detailed investigation into the mass and energy balance of the system was undertaken using operating data to determine why the flow rate discrepancies exist. A calculation of the mass and energy into and out of the system determined the actual flowrate at the fume burner inlet. A mass and energy balance of the fume burner and the stack was conducted, using independent data from the stack monitoring system. The mass and energy calculation determined that the instrument flow rate reading at the fume burner was about 20 percent of the actual rate. This affected the fume burner residence time, the fume burner temperature, and other aspects of the system performance. A number of other conclusions were reached from analysis of the mass and energy balance:

- The energy balance shows that the fume burner provided more than the design capacity for heating. The problems encountered maintaining the design temperature in the fume burner were caused by much higher flow rates to the fume burner than expected.

- A higher flow rate in the fume burner required higher flows of cooling air in the mixing chamber, which was double the design amount to maintain cooling in the mixing chamber discharge. This additional flow required the exhaust fans to operate at a higher flow rate than planned.

- The residence time calculated after operation was lower than that recorded by the process control system based upon the flows measured by the flow instrument at the fume burner inlet.

After March 9 with the continuous flow monitor in place, some problems were encountered maintaining the fume burner at 2,000 °F and driving the temperature beyond 2,000 °F. The false low reading on the continuous flow device at the fume burner inlet affected the fume burner's capacity for heating, which is dependent on the quantity of process flow that must be heated. Prior to March 9, a pitot tube was utilized to measure the fume burner inlet flow, and the temperature criterion was met with greater ease.

Although design criteria for the fume burner were not completely met during the field demonstration, the agent monitoring results show that the functional requirement for the field demonstration was met, since no agent was detected in the exhaust gas. These results indicate that the design criteria were sufficiently conservative to meet functional requirements, and to overcome equipment failures and unforeseen circumstances during operation.

The pressure measured at the fume burner is presented in Figure 6.20. This data indicates that the negative pressure at the fume burner was maintained throughout the field demonstration, except for some instantaneous excursions into the positive pressure range. These were apparently the result of adjustments in the mixing chamber cooling inlet, which created brief excursions and were corrected immediately.

Mixing Chamber

The temperature of the mixing chamber discharge is shown in Figure 6.21. This data indicates that the mixing chamber was operated for much of the HGDS well beyond its design criterion of 575 °F. The mixing chamber was consistently operated in the neighborhood of 800 °F to 900 °F, as a result of the balance which was maintained during operation between cooling air inlet flow in the mixing chamber, and negative pressure in the primary containment and secondary containment. It is noted that negative pressure is reduced when the cooling air valve is opened wider. The temperature of the mixing chamber outlet was permitted to creep higher than expected, in order to maintain negative system pressures. The temperatures that were reached (800 °F- 900 °F) approach the maximum limit for the materials of construction (carbon steel) of the discharge system. Most of the problems associated with the mixing chamber temperature are attributable to the faulty flow instrument at the fume burner inlet, and unseasonably warm ambient temperatures.

Radiator

The radiator was designed to reduce the temperature of the fume burner/mixing chamber discharge from 575 °F to 120 °F, to protect the carbon filter media from excess temperature when the system was in the Backup Mode. The radiator was used during initial heatup of the system when the fume burner was ramping up, during a brief excursion during operation when the fume burner dipped below temperature criteria, and during final cooldown, when the system was switched to the Backup Mode. The duty of the radiator during the field demonstration is presented in Figure 6.22. During all three occasions when

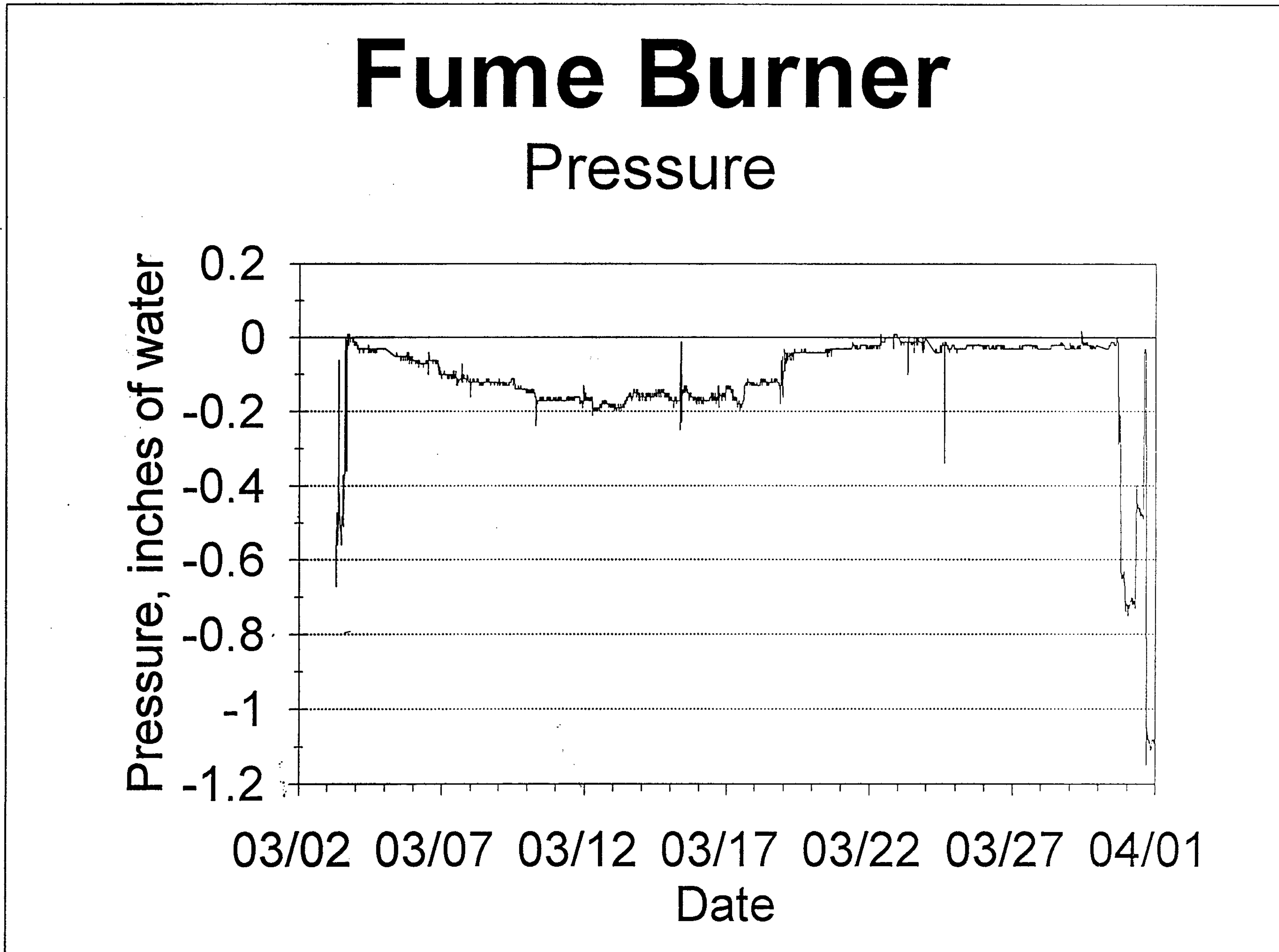

Fume Burner
Pressure
Pressure, inches of water
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
03/02 03/07 03/12 03/17 03/22 03/27 04/01
Date

FIGURE 6.20

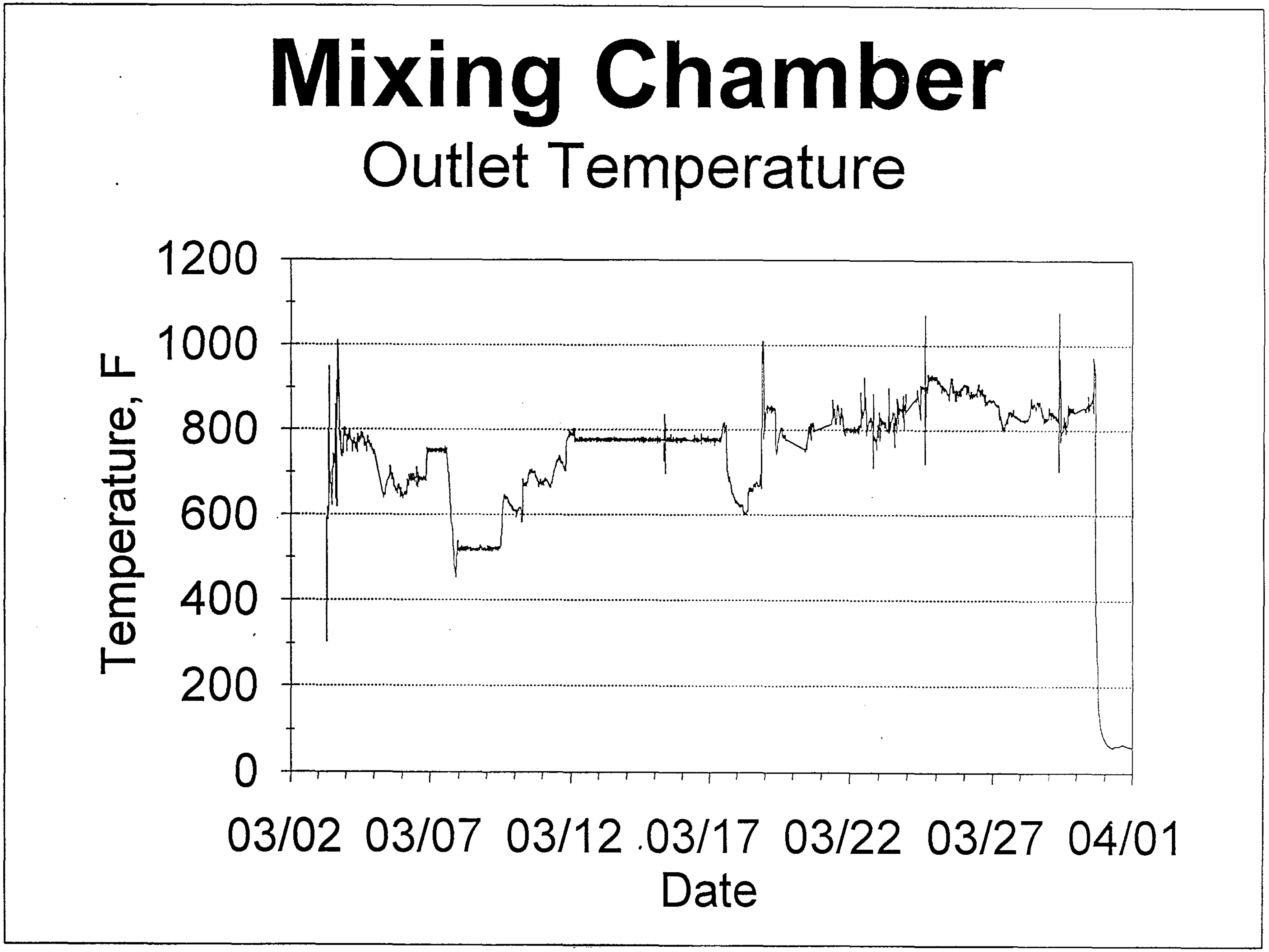

Mixing Chamber
Outlet Temperature
Temperature, F
1200
1000
800
600
400
200
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.21

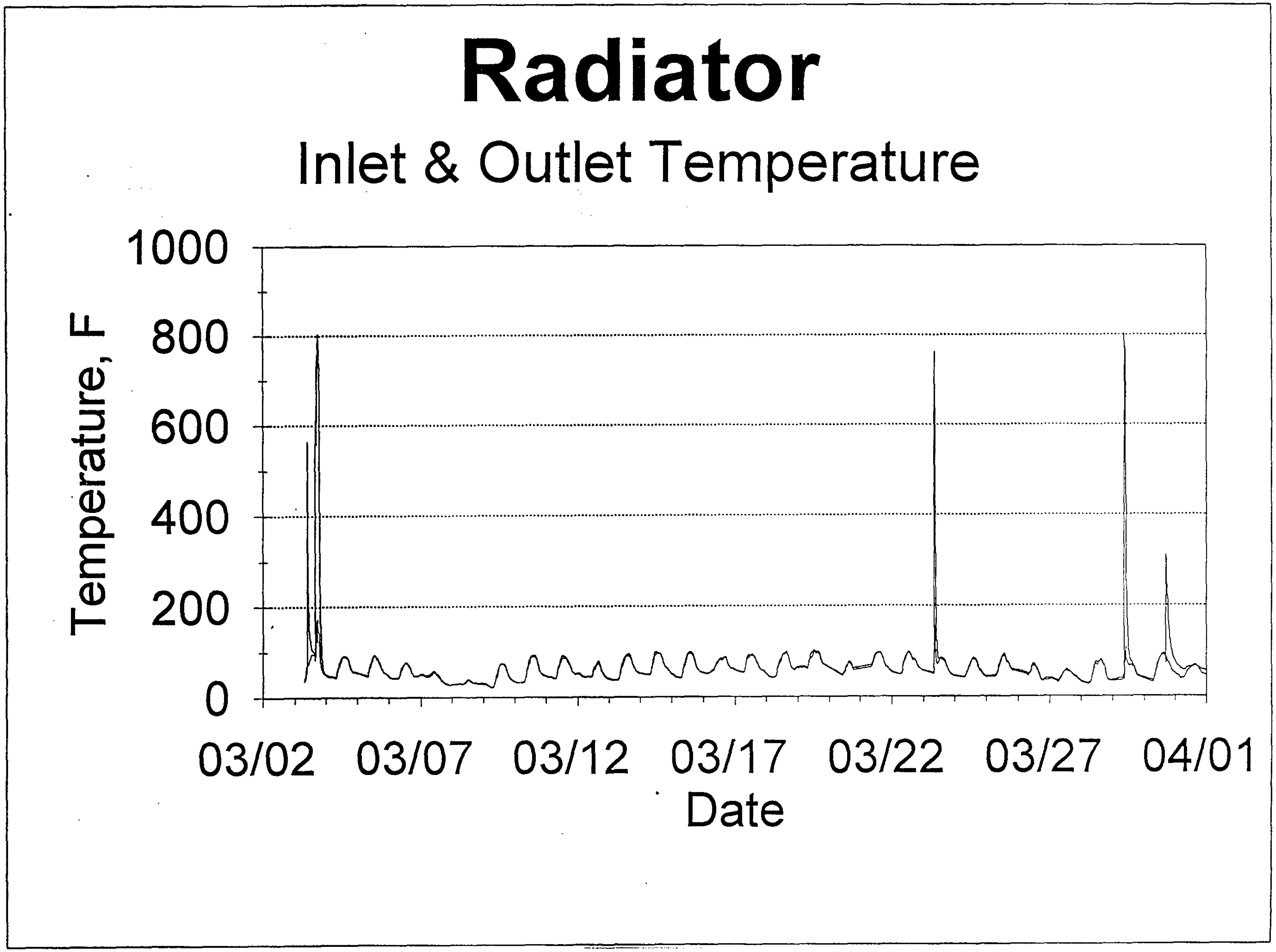

Radiator
Inlet & Outlet Temperature
Temperature, F
1000
800
600
400
200
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.22

the radiator was placed on-line, the design temperature criterion for operation was exceeded. The reason for this excursion was the higher-than-expected temperatures from the mixing chamber, which were required to maintain negative pressure. More detail is presented on Figure 6.23, which show results of a performance test at design criteria, followed by operation at a higher temperature. This data indicates that the radiator met its performance objectives in the test and reduced the temperature of the process gas from 575 °F to around 70 °F. When the inlet temperature hit 800 °F, the radiator cooled the gas to around 180 °F.

Carbon Filter

The carbon filter served the dual purpose as full-time treatment of the secondary containment ventilation air, and as the prime treatment unit in the Backup Mode. The design criterion for inlet to the carbon filter was set at 120 °F, due to temperature limitations of the carbon filter media. This value was calculated based on an outside ambient temperature of 40 °F during winter operation. When the ambient temperature during the field demonstration exceeded 70 °F, the temperature inside the secondary containment was higher than design criterion, and the inlet to the carbon filter peaked near 140 °F. In addition, several excursions to 140 °F were incurred in the Backup Mode as described above, noting that some cooling is gained in the ductwork from the radiator to the carbon filter. A temperature profile of the carbon filter inlet is presented in Figure 6.24.

The granulated carbon media loses removal efficiency above 130 °F, but is not subject to damage until approximately 600 °F. The carbon filter manufacturer was closely consulted during the period when the inlet temperature exceeded 130 °F, and indicated that no damage or serious loss of efficiency would be incurred at 140 °F. No breakthrough of the carbon filter was detected at the midway monitoring point or damage to the media was found during the field demonstration.

The amount of flow through the carbon filter during the field demonstration is presented in Figure 6.25. Although the design criteria for temperature to the carbon filter was exceeded, the functional requirement of preventing contaminant breakthrough of the carbon unit was achieved.

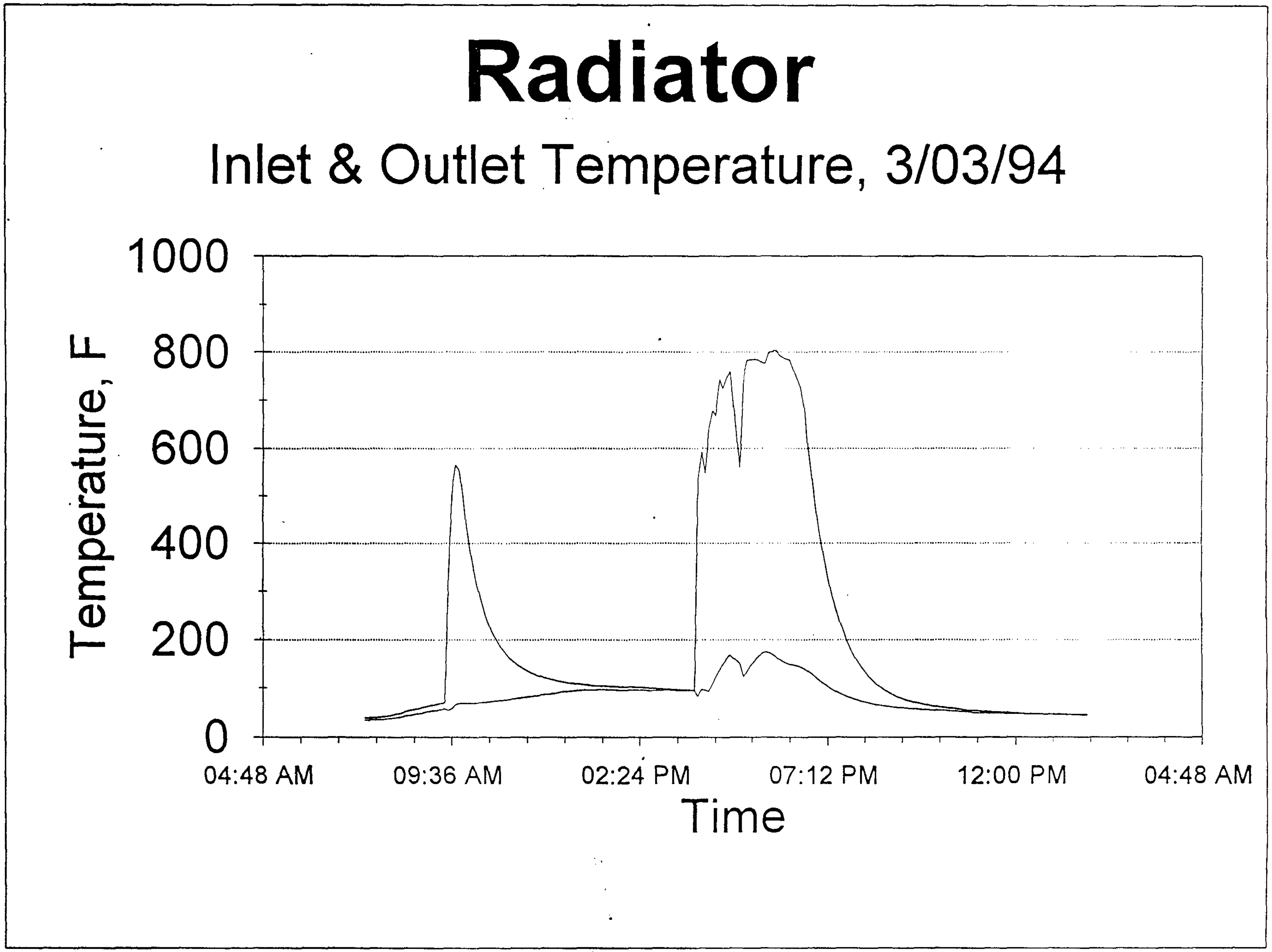
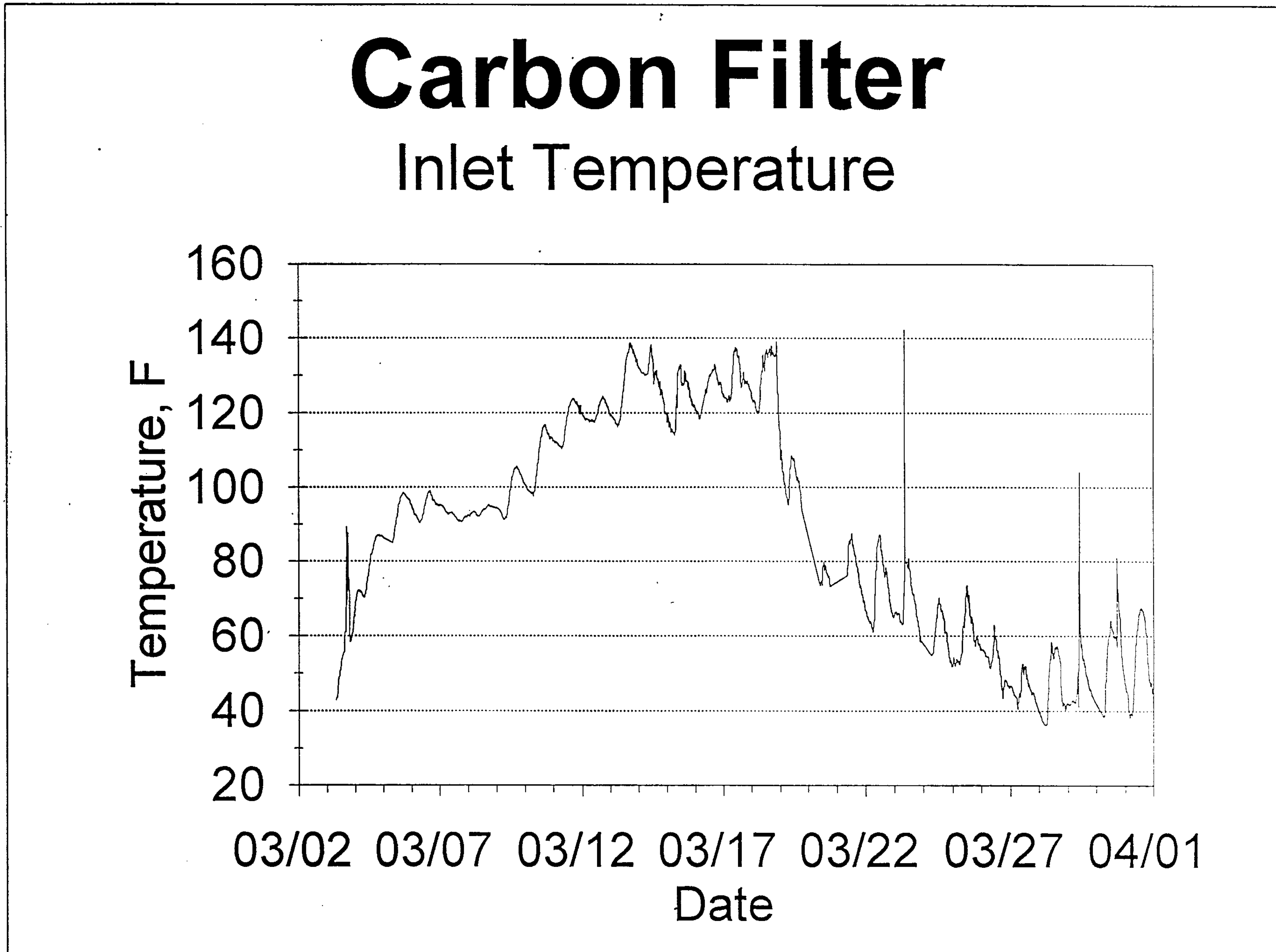
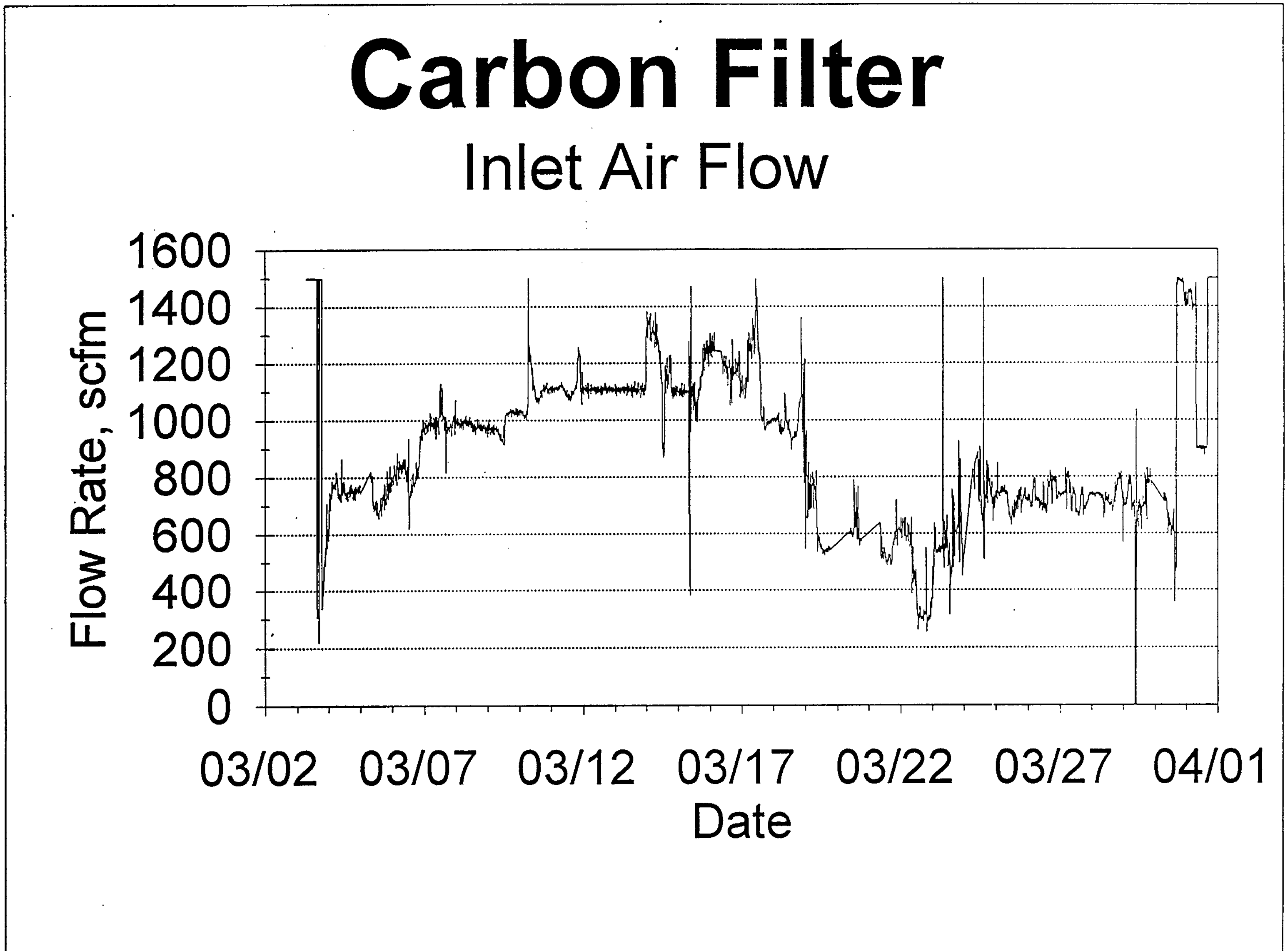

Radiator
Inlet & Outlet Temperature, 3/03/94
Temperature, F
1000
800
600
400
200
0
04:48 AM
09:36 AM
02:24 PM
07:12 PM
12:00 PM
04:48 AM
Time

FIGURE 6.23



Carbon Filter
Inlet Temperature
Temperature, F
160
140
120
100
80
60
40
20
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.24



Carbon Filter
Inlet Air Flow
1600
1400
1200
1000
800
600
400
200
0
Flow Rate, scfm
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.25

Secondary Containment

The functional requirement for the secondary containment area was to provide an enclosure to prevent the escape of volatilized contaminants from the pit and surrounding area to the atmosphere. Environmental protection and worker health and safety were the primary drivers for this requirement. A negative air pressure inside the secondary containment created in-leakage to the process system (carbon filter), rather than outward to the environment. The design criterion was set at -0.25 inches WG of negative pressure in secondary containment to ensure that potential leaks were pulled inward, and ventilation air from secondary containment was treated in the carbon filter.

The pressure inside secondary containment during the field demonstration is presented in Figure 6.26. A negative pressure near -0.1 inches WG was maintained during heatup. During cooldown, the pressure was maintained at a less negative amount (near -0.05 inches WG), to facilitate timely cooling of the pit. The porous nature of the cinder block building made -0.25 inches of WG an unattainable goal, despite efforts to seal the building and adjust the system operation to meet this set point.

The temperature inside the secondary containment is presented in Figure 6.27. The temperature peaked at 160 °F, and exceeded the expected design criterion, mostly due to unseasonably warm ambient temperatures during operations. The design criterion for temperature in secondary containment was 120 °F, with a maximum of 130 °F to protect the carbon filter media from damage or loss of efficiency. The functional requirement for negative pressure was met throughout the field demonstration, since the system was operated under negative pressure at all times, and there was no evidence of release from secondary containment. No damage to the secondary containment wall was observed after the field demonstration.

Minicams monitored the ambient air on the east and west sides of the secondary containment and in the control trailer. No confirmed release of mustard agent was detected in any of the Minicams.

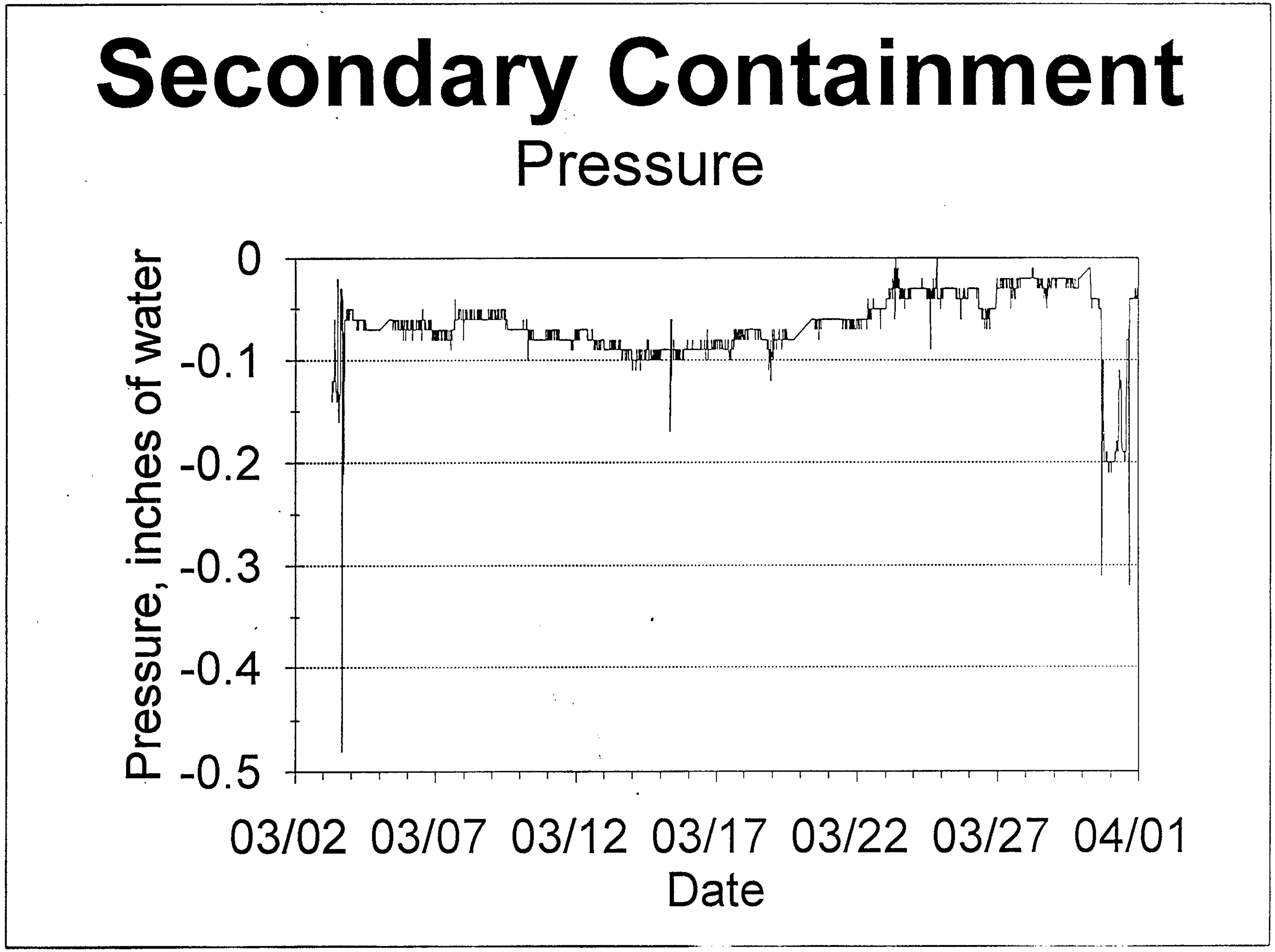

Secondary Containment
Pressure
Pressure, inches of water
0
-0.1
-0.2
-0.3
-0.4
-0.5
03/02 03/07 03/12 03/17 03/22 03/27 04/01
Date

FIGURE 6.26

Secondary Containment

Temperature

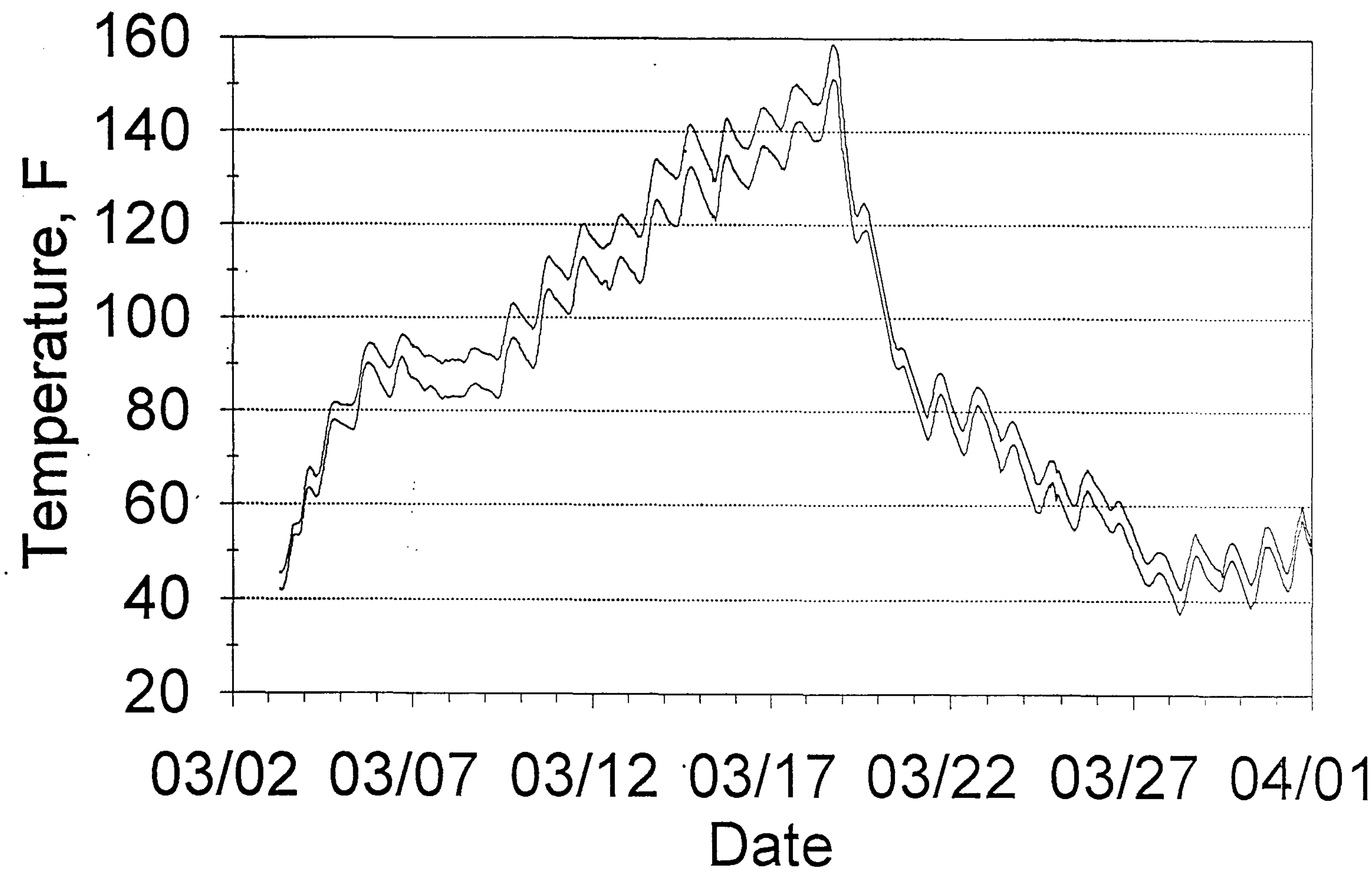


FIGURE 6.27

Induced Draft (ID) Fans

The flow rate through the induced draft fans and the exhaust system is presented in Figure 6.28. The north and south fan flow rates are shown in greater detail in Figures 6.29 and 6.30 respectively. Higher flow rates than expected in the design were experienced due to efforts to maintain negative pressure, and the false low instrument reading for pit gas flowing to the fume burner. Because the cinder block walls of the secondary containment were more porous than anticipated, higher air flows were required to maintain negative pressure in both secondary and primary containments. At times, flows were as much as 40 percent higher than the original design requirement to meet system requirements.

After initial startup, the ID fans produced 4,800 SCFM total exhaust flow, or 41 percent over the design value of 3,400 SCFM. Just prior to heat soak, the flows dropped to 4,150 SCFM as concrete temperatures began to approach 350 °F.

The most taxing flow condition for the ID fans occurred in the Backup Mode when the process exhaust was completely diverted through the radiator and carbon filter. This can be observed during the late cooldown phase, when the Backup Mode was on-line.

Structural Integrity

A functional requirement of the HGDS was to avoid structural damage to Building 537 by properly managing the heat flow.

To protect the building structure from damage, the maximum temperature gradient in any section of concrete wall or floor was not to exceed 200 °F per foot of concrete thickness. Thermocouple data shows that the temperature gradient criterion of 200 °F per foot of concrete was met for all structural loading bearing areas of the pit. However, during operation this criteria was relaxed for non-load bearing walls, to facilitate timely performance of the field demonstration.

During operation, the temperature gradient in the west side of the pit next to the ventilation tunnel approached the maximum gradient, and inhibited heat input to the entire pit. This was caused by the increased heat transfer

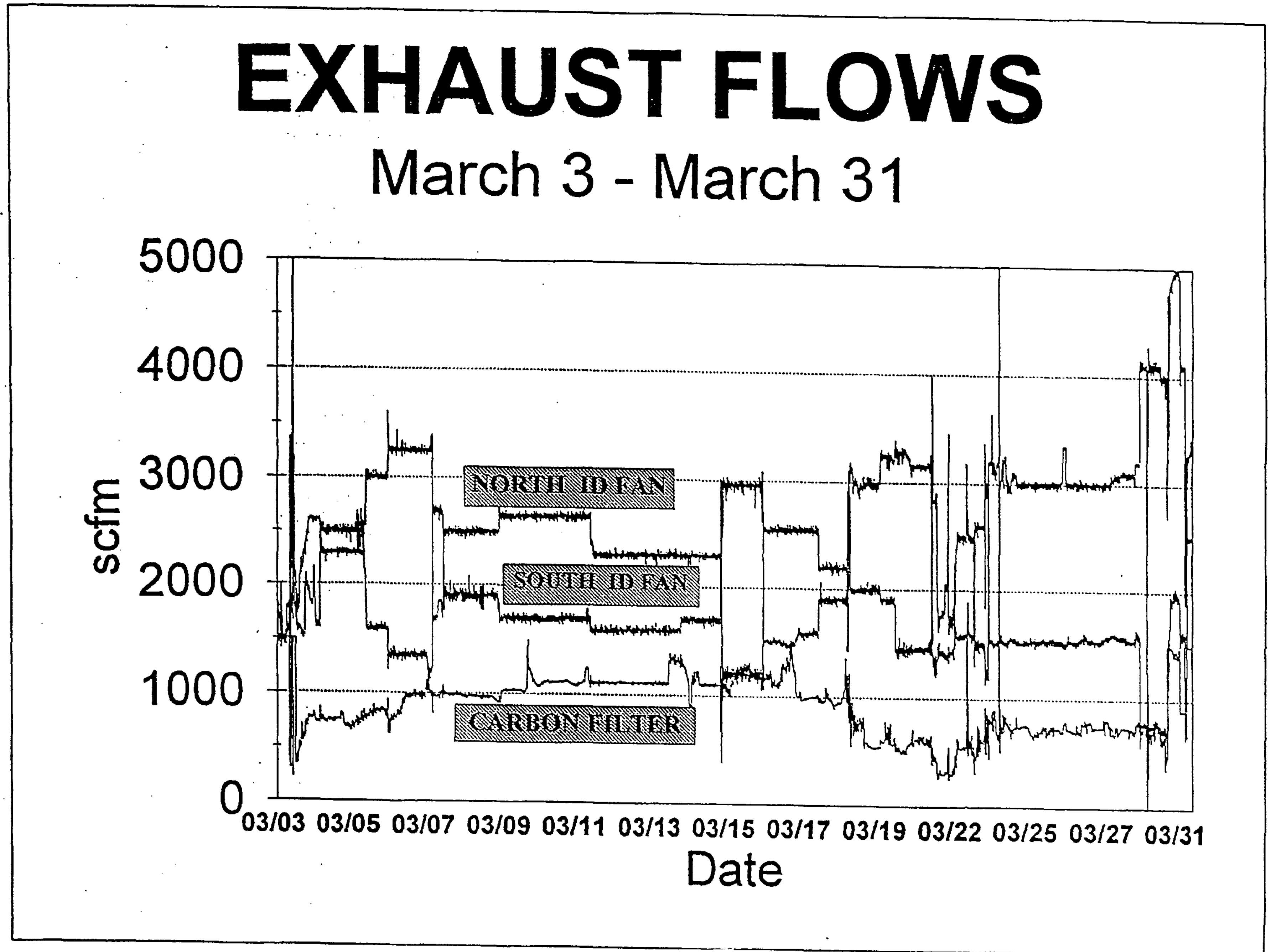

EXHAUST FLOWS
March 3 - March 31
scfm
5000
4000
3000
2000
1000
0
NORTH ID FAN
SOUTH ID FAN
CARBON FILTER
03/03 03/05 03/07 03/09 03/11 03/13 03/15 03/17 03/19 03/22 03/25 03/27 03/31
Date

FIGURE 6.28

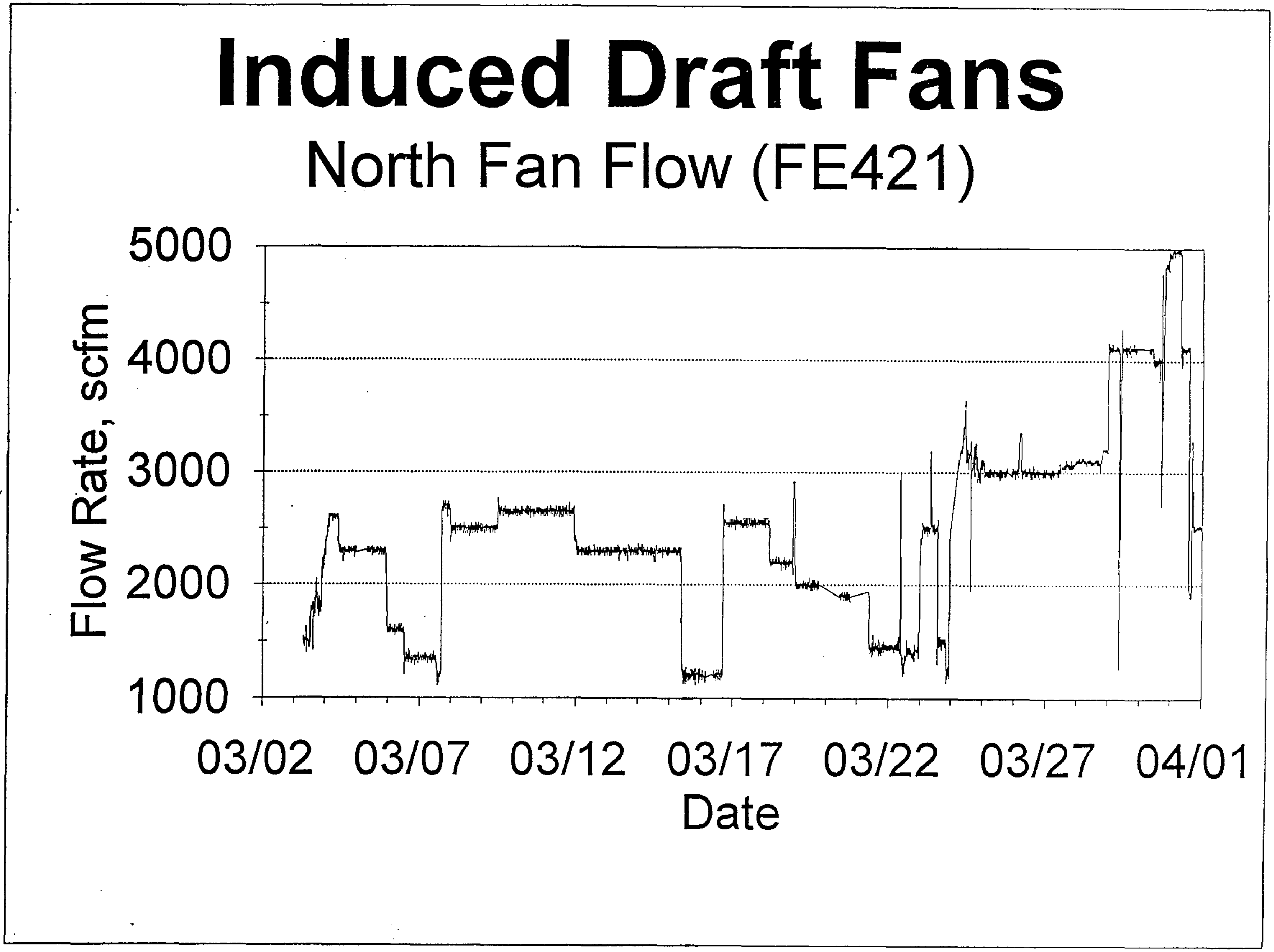

Induced Draft Fans
North Fan Flow (FE421)
Flow Rate, scfm
5000
4000
3000
2000
1000
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.29

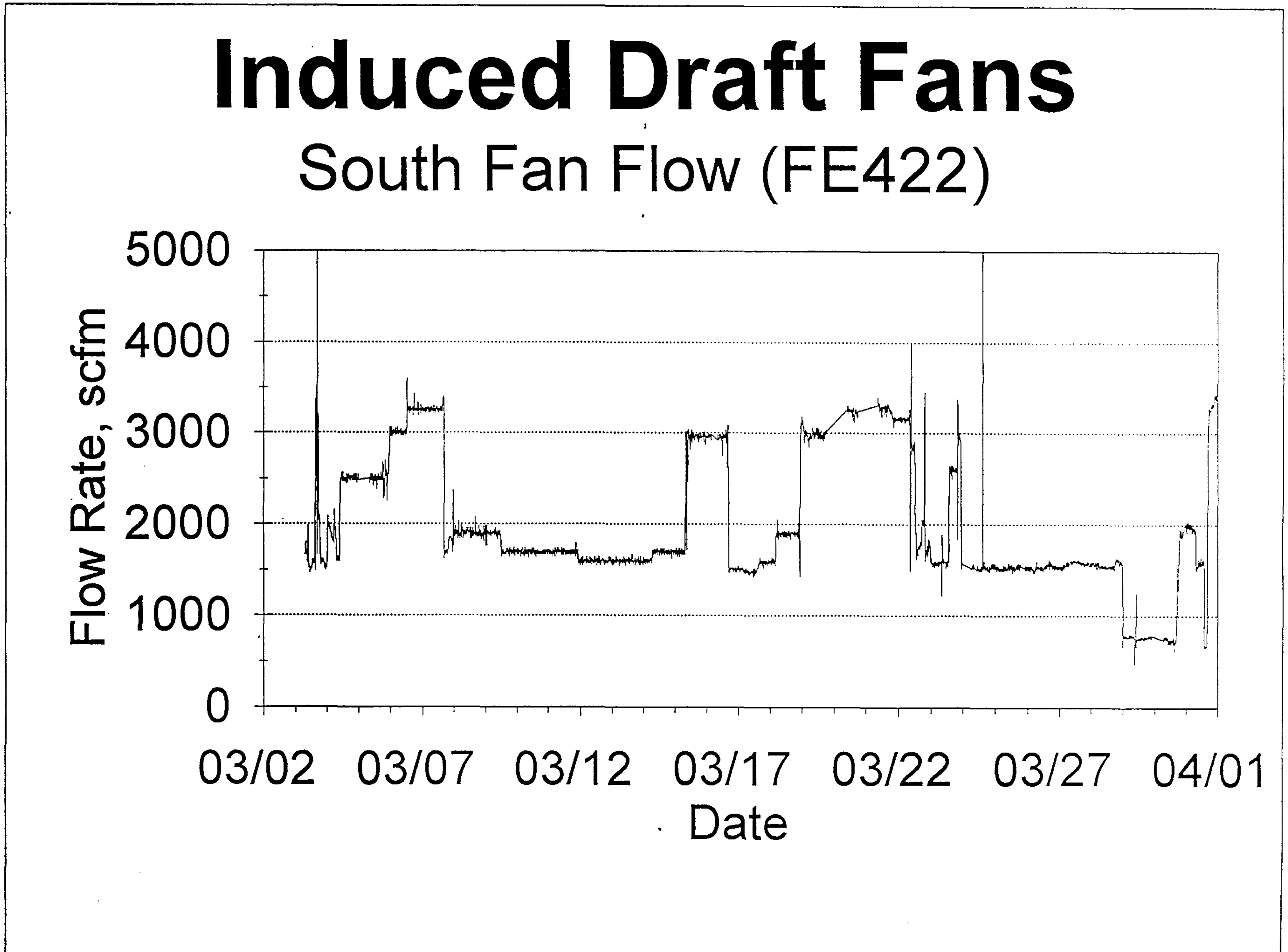

Induced Draft Fans
South Fan Flow (FE422)
Flow Rate, scfm
5000
4000
3000
2000
1000
0
03/02
03/07
03/12
03/17
03/22
03/27
04/01
Date

FIGURE 6.30

through the west wall due to the open space behind the wall. The decision was made to allow a higher temperature gradient on the west side of the pit, providing the gradient was below 200 °F per foot on the east load-bearing wall. Using this approach, the field demonstration was completed with no known structural damage. A visual inspection of the condition of parts of the pit structure was undertaken during the core sampling operation. Inspection was possible only in locations where core samples were taken, where the steel plenum was removed. The steel plenum has been removed in sampling locations only, but not for the entire pit. This partial inspection revealed no damage to the pit structure or concrete. During decommissioning of the Hot Gas system, a complete structural inspection of the pit is recommended.

System Performance Summary

The overall operational performance of the system is rated as very good, since the functional requirements for the project were met. The fact that the design criteria were not met in all cases is of secondary importance, since the field demonstration met its functional objectives. This indicates that the design criteria were sufficiently conservative to overcome unknown problems and conditions encountered in a rigorous test of an innovative technology.

7.0 COST ANALYSIS/COST COMPARISON

7.1 GENERAL

The cost for the field demonstration of the HGDS, from design through operation, was $5.9 million. An adjusted cost, which subtracts costs incurred due to project delays, was $5.3 million, and is considered the real cost of the project. A summary and discussion of the project cost and a cost comparison to the demolish and incinerate alternative are presented below.

7.2 COST REPORT

Cost information from all participating organizations was utilized to determine the final project cost for the field demonstration. Costs incurred for pre-design planning, design, procurement, construction and operation of the HGDS are included. The final cost of $5.9 million is categorized by phase of work as follows.

Cost Breakdown by Project Phase

Planning, Design, and Report Costs:	$1,211,300
Construction and Procurement Labor Costs:	$1,633,400
Material and Equipment Costs:	$1,837,200
Operations, Operations Planning/Management:	$1,196,600
Total Cost for the Field Demonstration	$5,878,500
	or ($5.9 million)

A line item breakdown of costs for process equipment and materials is presented in Table 7.1.

It should be noted that two unplanned delays inflated the overall project cost. Both delays were not attributable to this project, and were beyond the control of the project team. The first was a 9 month funding delay which resulted from diversion of funding during Operation Desert Storm. The

TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES QTY	QUANTITIES UNIT	UNIT COSTS MATL	MATERIAL EXPENSE	RENTAL COSTS UNIT	RENTAL COSTS DOLLARS		TOTAL DOLLARS
	SUMMARY								
1	STRUCTURAL/ARCHITECTURAL				73,503		2,865		76,368
2	MECHANICAL SPECIALTIES				8,663				8,663
3	PROCESS EQUIPMENT				393,548				393,548
4	ROTATING EQUIPMENT				36,729				36,729
5	FUEL SYSTEM SERVICE CONNECTION						675		675
6	INSTRUMENTATION				422,849				422,849
7	ELECTRICAL				73,595		53,980		127,575
8	INSTRUMENT AIR SUPPLY				1,006		2,400		3,406
9	MECHANICAL PIPING				84,212				84,212
10	AGENT AND EMISSIONS MONITORING				494,000				494,000
11	CONSTRUCTION CONSUMABLES & SUPPLIES				189,175				189,175
	TOTAL				0		59,920		1,837,200

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TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES QTY	QUANTITIES UNIT	UNIT COSTS MATL	MATERIAL EXPENSE	RENTAL COSTS UNIT	RENTAL COSTS DOLLARS		TOTAL DOLLARS
1	STRUCTURAL/ARCHITECTURAL								
1.1	HOT GAS PLENUM AND STRUCTURE	1810	SF	14	25,340				25,340
1.2	PRIMARY CONTAINMENT COVER W/WALLS	30	LS	1196	35,880				35,880
1.3	SECONDARY CONTAINMENT WALL	1525	SF		5,678				5,678
1.4	CONTROL/DAS TRAILER – 6 MO RENT	1	LOT		0		2,865		2,865
1.5	PIPE ANCHOR – SHEET S–1–8	3558	LBS	1	1,815				1,815
1.6	CRIBBING FOR EQUIPMENT	43.00	LOT	30	1,290				1290
	SUBTOTAL				70,003				
	FREIGHT (EX. TRAILER)	5	%		3,500				3,500
	STRUCTURAL/ARCHITECTURAL TOTAL				73,503		2,865		76,368

TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES QTY	QUANTITIES UNIT	UNIT COSTS MATL	MATERIAL EXPENSE	RENTAL COSTS UNIT	RENTAL COSTS DOLLARS		TOTAL DOLLARS
2	MECHANICAL SPECIALTIES								
2.1	DAMPER 24X24	1	EA	252	252				252
2.2	DAMPER SEALS	1	EA	85	85				85
2.3	LOUVER 12X12	1	EA	75	75				75
2.4	FLASHING COLLARS FOR DAMPER/LOUVER	1	EA	188	188				188
2.5	RETURN AIR DUCT 18"X12", 16 GA, 4–90° ELS								
	4 REDUCERS AND SUPPORTS	150	LF	51	7,650				7,650
	SUBTOTAL				8,250				
	FREIGHT	5	%		413				413
	MECHANICAL SPECIALTIES TOTAL				8,663				8,663
3	PROCESS EQUIPMENT								
3.1	MAIN BURNERS (2) GAS TRAINS	1	LOT	247,795	247,795				247,795
	FUME BURNER & MOVING CHAMBER								
3.2	CARBON FILTER	1	EA	61,393	61,393				61,393
3.3	RADIATOR	1	EA	58,700	58,700				58,700
3.4	STACK	1	EA	6,920	6,920				6,920
	SUBTOTAL			374,808	374,808				374,808
	FREIGHT	ERR	ERR	18,740	18,740				18,740
	PROCESS EQUIPMENT TOTAL				393,548				393,548

022–I:\723542\32.WK1

TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES QTY	QUANTITIES UNIT	UNIT COSTS MATL	MATERIAL EXPENSE	RENT COSTS UNIT	RENT COSTS DOLLARS		TOTAL DOLLARS
4	ROTATING EQUIPMENT								
4.1	RECIRCULATION FAN	1	EA	4,470	4,470				4,470
4.2	INDUCED DRAFT FAN	2	EA	12,905	25,810				25,810
4.3	INLET BOX FOR ID FANS	2	EA	720	1,440				1,440
4.4	INLET DAMPER FOR ID FANS	2	EA	1,630	3,260				3,260
	SUBTOTAL				34,980				34,980
	FREIGHT	5	%		1,749				1,749
4	ROTATING EQUIPMENT TOTAL				36,729				36,729
5	FUEL SYSTEM								
	NATURAL GAS SERVICE CONNECTION	1	EA		0	METER	675		675
5	FUEL SYSTEM TOTAL						675		675

TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES		UNIT COSTS	MATERIAL	RENTAL COSTS			TOTAL
		QTY	UNIT	MATL	EXPENSE	UNIT	DOLLARS		DOLLARS
6	INSTRUMENTATION								
6.1	D/P TRANSMITTERS	1	LOT	10,020	10,020				10,020
6.2	MASS FLOW METERS SINGLE	8	EA	3,327	26,616				26,616
6.3	MASS FLOW METERS MULTI	2	EA.	7,855	15,710				15,710
6.4	PRESSURE GAUGES	9	EA	433	3,897				3,897
6.5	PRESSURE SWITCHES	2	EA	388	776				776
6.6	PRESSURE TRANSMITTER	5	EA	1,005	5,025				5,025
6.7	TEMP TRANSMITTERS	1	LOT	12,130	12,130				12,130
6.8	THERMOMETERS	5	EA	175	875				875
6.9	MAIN CONTROL PANEL & I/O CABINETS	1	LOT	33,290	33,290				33,290
6.10	PLC SYSTEM	1	LOT	74,553	74,553				74,553
6.11	COMPUTER	1	LOT	16,661	16,661				16,661
6.12	PLC PROGRAMMING SOFTWARE	1	EA	1,805	1,805				1,805
6.13	PROCESS CONTROL SOFTWARE	1	EA	5,171	5,171				5,171
6.14	PROCESS CONTROL PROGRAMMING	1	EA	43,600	43,600				43,600
6.15	TV-400 MIX CHAMBER TEMP CONTROL 12"	1	EA	20,000	20,000				20,000
6.15	XV 401 RETURN AIR MIX CHAMBER	1	EA	20,000	20,000				20,000
6.15	XV-402 MIX CHAMBER TO RADIATOR 20"	1	EA	11,293	11,293				11,293
6.16	FV-405 CONTAINMENT AIR 12"	1	EA	7,128	7,128				7,128
6.16	XV-406 RADIATOR DISCH 20"	1	EA	11,293	11,293				11,293
6.16	XV-412 MIX CHAMBER TO EXH 20"	1	EA	11,293	11,293				11,293
	PAGE TOTAL				331,136				331,136

TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES QTY	QUANTITIES UNIT	UNIT COSTS MATL	MATERIAL EXPENSE	RENTAL COSTS UNIT	RENTAL COSTS DOLLARS		TOTAL DOLLARS
6	INSTRUMENTATION (CONT)								
6.16	XV-414 CARBON FILTER TO EXH 20"	1	EA	11,293	11,293				11,293
6.16	FV-314 FUME BURNER AIR 6"	1	EA	2,995	2,995				2,995
6.16	FV-324 FUME BURNER AIR 6"	1	EA	2,995	2,995				2,995
6.16	FV-204 RECIRCULATION AIR 18"	1	EA	10,335	10,335				10,335
6.16	HV-205 BYPASS 12"	1	EA	7,128	7,128				7,128
6.16	HV-206 12"	1	EA	7,128	7,128				7,128
6.16	HV-207 12"	1	EA	7,128	7,128				7,128
6.16	HV-208 12"	1	EA	7,128	7,128				7,128
6.16	FV-125 4"	1	EA	2,668	2,668				2,668
6.17	PCV-301 MAIN GAS-FUME BURNER	1	EA	475	475				475
6.17	PCV-303 PILOT GAS-FUME BURNER	1	EA	80	80				80
6.18	MISC CV HARDWARE	1	LOT	14,300	14,300				14,300
	PAGE SUBTOTAL				73,653				73,653
	SUBTOTAL				404,789				404,789
	FREIGHT (EXC. PROGRAMMING)	0.05			18,060				18,060
	INSTRUMENTATION TOTAL				422,849				422,849

TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES		UNIT COSTS	MATERIAL	RENTAL COSTS			TOTAL
		QTY	UNIT	MATL	EXPENSE	UNIT	DOLLARS		DOLLARS
7	ELECTRICAL								
7.1	MOTOR CONTROL CENTER PACKAGE	1	EA	56,000	56,000				56000
7.2	DISCONNECT SWITCH 480V, 30A	6	EA	216	1,296				1,296
7.3	DISCONNECT SWITCH 480V, 200A	2	EA	654	1,308				1,308
7.4	DISTRIBUTION PANEL 120/208V, 100A	3	EA	1391	4,173				4,173
7.5	3# 350 MCM W/1# 3 GND XHHW	340	FT	6.96	2,366				2,366
7.6	3# 3/0 W/ 1# 4 GND, XHHW	290	FT	3.95	1,146				1,146
7.7	3# 2 W/1 #6 GND, XHHW	70	FT	1.6	112				112
7.8	4 #2 W/1 #6 GND, XHHW	20	FT	2.11	42				42
7.9	3 #8 W/1 #10GND, XHHW	265	FT	0.66	175				175
7.10	4 #8 W/1 #10 GND, XHHW	150	FT	0.83	125				125
7.11	3 #10 W/1 #10 GND, XHHW	105	FT	0.55	58				58
7.12	3 #12 W/1 #12 GND, XHHW	925	FT	0.39	361				361
7.13	2 #12 W/1 #12 GND, XHHW	760	FT	0.29	220				220
7.14	2 #16 TWISTED PAIR W/SHIELD	590	FT	0.38	224				224
7.15	4/0 BARE COPPER	100	FT	1	139				139
7.16	PUBLIC ADDRESS SYSTEM	1	EA	768	768				768
7.17	CABLE BRIDGE	6	EA	263	1,578				1,578
7.18	DIESEL GENERATOR, 500KVA, RENTAL	2	EA	3,952		4 MOS	31,620		31,620
7.19	LIGHT TRAILER RENTAL	2	EA	795		4 MOS	6,360		6,360
7.20	UPS 30 KVA	1	EA	4,000		4 MOS	16,000		16,000
	SUBTOTAL				70,091				
	FREIGHT (LESS RENTAL)	5	%		3,505				3,505
7	TOTAL ELECTRICAL				73,595		53,980		127,575

TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES QTY	QUANTITIES UNIT	UNIT COSTS MATL	MATERIAL EXPENSE	RENTAL COSTS UNIT	RENTAL COSTS DOLLARS		TOTAL DOLLARS
8	INSTRUMENT AIR SUPPLY								
8.1	INSTRUMENT AIR SUPPLY – RENTAL	6	MO	400			2,400		2,400
8.2	SKID LUMBER	1	LS	204	204				204
8.3	SKID STEEL	1	LS	52	52				52
8.4	SKID UNISTRUT	1	LS	91	91				91
8.5	INSTRUMENT AIR PIPING 1" W/FITTINGS	1	LS	611	611				611
	SUBTOTAL				958				
	FREIGHT (LESS RENTAL)	5	%		48				48
8	INSTRUMENT AIR SUPPLY TOTAL				1,006		2,400		3,406
9	MECHANICAL PIPING								
9.1	LARGE CARBON STEEL PIPE & FITTING	1	LOT	45,351	45,351				45,351
9.2	NG PIPE AND FITTINGS	1	LOT	1,464	1,464				1,464
9.3	SS PIPE AND FLANGES	1	LOT	4,167	4,167				4,167
9.4	EXPANSION JOINTS	1	LOT	14,551	14,551				14,551
9.5	PIPE SUPPORTS	1	LOT	14,669	14,669				14,669
	SUBTOTAL				80,202				80,202
	FRAIGHT	5	%		4,010				4,010
9	MECHANICAL PIPING TOTAL				84,212				84,212

TABLE 7.1 MAJOR EQUIPMENT AND MATERIALS

COST SHEET FOR THE HOT GAS DECONTAMINATION SYSTEM

ITEM NUMBER	DESCRIPTION	QUANTITIES		UNIT COSTS	MATERIAL	RENTAL COSTS			TOTAL DOLLARS
		QTY	UNIT	MATL	EXPENSE	UNIT	DOLLARS		
10	AGENT AND EMISSIONS MONITORING								
10.1	MINICAMS				265,000				265000
10.2	EMISSIONS MONITORS AND DAS				229,000				229,000
	AGENT & EMISSIONS MONITORING TOTAL				494,000				494,000
11	CONSTRUCTION CONSUMABLES & SUPPLIES								
11	TOTAL								189,175

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second was a delay requested by Program Manager Rocky Mountain Arsenal due to public concern regarding another, unrelated project at the Arsenal. This second delay was particularly untimely and expensive, since it occurred during construction, and involved complete demobilization and remobilization of the construction contractor and management. Extra cost was incurred for labor force piece-meal work, stand-by time, extra construction management and equipment rentals. Combined, the cost impact of the delays has been estimated to be $600,000. When taken into consideration, this amount would reduce the overall project cost to $5.3 million.

7.3 COST DISCUSSION

It should be noted that other factors tended to inflate the HGDS cost, in addition to the two unplanned delays.

As a research and development project for an unproven innovative technology, extra costs were incurred during all phases of the work, when compared to a more common treatment facility. Planning and design costs for the HGDS were higher than for common technologies due to the additional planning and design required on R&D for a new technology.

More than the usual number of meetings, coordination, and approvals were required. As an R&D project, the system was highly instrumented and monitored to report on project results, much more so than a normal production plant. Safety systems were more substantial in the HGDS to prepare for unforeseen events. These factors contributed to significant extra cost.

Many lessons learned on this R&D effort could be avoided on the next project. The cost of repairs, troubleshooting and maintenance attributable to the R&D effort is estimated to be $350,000. For example, ID fan repairs and maintenance contributed to a project delay of seven weeks. During this time, all labor forces remained mobilized.

Other site-specific considerations drove the project cost higher, and may not be encountered on future projects.

The project was a retrofit to an existing facility in close space quarters. A large number of field changes (engineering and construction) were required to field-fit purchased equipment, which was larger than originally expected. Also, the target site was surrounded by contaminated ground, equipment and structures. This caused special design and construction of large containment areas and safety systems.

The HGDS equipment is reusable and can be relocated, which reduces the long-term capital cost on a single project. When used at multiple sites, the cost of process equipment and salvageable materials is spread over several projects.

Future projects should benefit from the operational and technical experience gained on the HGDS project. This will contribute to cost savings in the future. Also, future projects targeting contaminants which are less toxic than chemical agent may realize cost savings when compared to this effort.

7.4 COST COMPARISON

To provide an economic evaluation of the relative cost of the HGDS, a cost comparison was undertaken. The cost incurred on the HGDS was compared to the estimated cost of the available alternative technology (demolish and incinerate). The intent is to provide a realistic comparison of the Hot Gas technology to alternative technologies. The "demolish and incinerate" technology is currently the only alternative technology.

The concept design for the "demolish and incinerate" technology to decontaminate the mustard pit at Building 537 was developed. A detailed cost estimate based on this concept design was prepared and the estimated cost is $10.4 million.

The concept design for the "demolish and incinerate" alternative is based on criteria currently established by the U.S. Army for decontamination of structures. Demolition of agent contaminated structures must be performed under controlled ventilation according to Army regulation (DA Reg and Pam 385-61).

In order for decontaminated materials to be released from government control, thermal treatment (incineration) at a uniform temperature of 1,000 °F for 15 minutes is required. Materials exposed to such conditions are described as having attained "5X" rating status and are defined as suitable for unrestricted use (DA Reg and Pam 385-61). These requirements established the design criteria for the preliminary design of the process and equipment for the "demolish and incinerate" technology. To complete the technology and provide disposal of rubble from the structure, landfilling was added to the option.

A summary of the concept design of the "demolish, incinerate, and landfill" (DIL) technology is presented as follows.

Demolition of the mustard pit was performed within a secondary containment surrounding the area for environmental protection, and OSHA Level A and Level B Personal Protective Equipment (PPE) was used by workers for personal protection (as required). A continuous rotary kiln incinerator was selected with capability of 1,000 °F temperature for 15 minutes residence time. The demolition and process equipment are under negative pressure and a fume burner would destroy contaminants in the off-gas at 2,000 °F for 2 seconds residence time.

After the rubble is tested and verified as clean, it is landfilled in a standard landfill located onsite at Rocky Mountain Arsenal. No stockpiling of rubble was permitted. The landfill was assumed to be 3 miles from Building 537. More details of the DIL option is presented in Table 7.2, Basis of Cost Estimate.

A line item breakdown of materials and equipment costs for the DIL alternative is presented in Table 7.3. Work crew craft makeup and unit costs for work crews used in the estimate are presented in Table 7.4. For purpose of the DIL estimate, five crews were required. The crews were divided into teams required for different activities. Crew 1 consists of a Health and

TABLE 7.2

BASIS OF COST ESTIMATE FOR THE

"DEMOLISH, INCINERATE, AND LANDFILL" OPTION

- Treatment Technology consists of demolition, incineration, and landfilling (DIL).
- Performed on the Mustard Thaw Pit at Building 537, Rocky Mountain Arsenal
- Planning and Design costs are assumed to be the same as the Field Demonstration of the Hot Gas Decontamination System for estimating purposes.
- Same construction and labor teams as the HGDS are used. For estimating purposes, crews were divided into teams for each operation or stage.
- Level A and Level B PPE will be required for demolition. Full-time ventilation will be in place. Continuous air monitoring will be conducted.
- Some clearing and removal will take place as with the HGDS.
- Round-the-clock demolition and incineration may be required during certain stages due to operation or contamination requirements.
- Rotary kiln incinerator was chosen over a batch-type incinerator due to H&S handling concerns, and limitations during heatup and cooldown.
- Residence times for materials treated will meet 5X criteria (1,000 °F for 15 minutes). A fume burner (afterburner) will destroy off-gasses for 2 seconds at 2,000 °F.
- Treated materials will be landfilled on RMA property. No stockpiling of material will be permitted.
- Same redundancies and negative pressure will be applied to DIL system as in the HGDS.

TABLE 7.3

MATERIAL AND EQUIPMENT LINE ITEM BREAKDOWN COSTS FOR THE DIL ESTIMATE

SECONDARY CONTAINMENT	
Sealing of 537 Work Area	
Drywall and Studs	$3,500
Hypalon Fabric	$2,300
Sil-Temp Fabric	$900
Steel Plate	$50
Plywood Sheeting	$300
Installation of Entry	$6,000
Damper Installation	$400
VENTILATION SYSTEM	
For Secondary Containment	
Structure	$400
Fan	$6,500
Near Loading Area	
Structure	$400
Fan	$6,500
CONCRETE CRUSHING AREA	
Unit	$40,000
Pad	$1,000
Guards and Chute	$500
INCINERATION UNIT	
Main Unit	$1,650,000
Technical Support	$10,000
System Piping (NG)	$1,500
Unistrut Material	$100
Backup Burners (2)	$10,000
Backup ID Fan	$15,000
ADDITIONAL SYSTEM COMPONENTS	
Concrete Pad	$2,800
Backup System	
Mixing Chamber	$52,000
Radiator + Base	$59,100
Carbon Unit	$61,000
Gas Trains (3)	$62,000
System Piping	
Piping	$37,500

TABLE 7.3 (Cont'd)

ADDITIONAL SYSTEM COMPONENTS (Cont'd)	
System Piping (cont'd)	
Exp. Joints	$14,500
Flanges and Couplings	$800
Lumber and Posts	$250
Pipe Supports	$3,500
Unistrut	$100
Misc. Pipe and Fittings	$300
Stack	$10,100
Compressors (2)	$5,500
MCC	$40,400
UPS	$28,000
Generators (2)	$35,000
(Needed for duration of operation)	
Fuel for Generators	$25,000
Fuel Storage Tank	$2,200
Electrical Bulks	$8,500
Natural Gas	$13,300
Site and Area Lighting	$5,000
Misc. Site Materials and Equip.	
PA System	$850
Electrical Conductor	$1,700
C/ S Plate	$300
12 GA. Plate	$600
Aluminum Heat Tape	$2,200
Safety Equipment (General)	$800
INSTRUMENTATION AND CONTROLS	
Control Trailer	$2,700
Control System	
IBM computer	$9,500
Backup computer	$5,000
AB Software	$7,500
AB Interface Card and Cable	$1,200
AB Technical Support	$7,000
Epson Printer (2)	$2,200
Computer Interface Cable	$200
Control Valves	$60,000
Solenoid Valves	$400
Positioner	$1,300
Instrumentation	
Temperature Sensors	$8,300
Temperature Sensors	$8,300
Gas Pressure Regulators	$900

TABLE 7.3 (Cont'd)

INSTRUMENTATION AND CONTROLS (Cont'd)

Instrumentation (Cont'd)	
Pressure Switches	$3,300
PTs and DPTs	$18,000
Mass Flow Meters	$34,600
PLC and I/O Cabinets	$98,300
Instrumentation Valves	$7,700
Pressure Switch	$100
Misc. Electrical	$1,500
Radio Rentals	$200
Pager Rentals	$100
Flow Meter	$4,400
Flow Meter Calibration	$4,000
Hose and Materials	$1,500
Safety Switch	$2,400

DAILY DECONTAMINATION

Decon line for Personnel	$400
Decon area for equipment	$600

TABLE 7.4 CREW LABOR AND EQUIPMENT COSTS FOR DIL PROJECT

Work weeks are defined as 12 hours a day/7 days a week.

Crew 1	
Health and Safety Officer	Unit Cost: $720/day
Level B (1/2 Time)	Unit Cost: $100/day
Level C (1/2 Time)	Unit Cost: $35/day
(3) Minicam Units	Unit Cost: No Cost
(2) Ventilators	Unit Cost: $10/day
ODCs	Unit Cost: $10/day
Contractor Foreman	Unit Cost: $720/day
Level B (1/2 Time)	Unit Cost: $100/day
Level C (1/2 Time)	Unit Cost: $35/day
ODCs	Unit Cost: $10/day
	Crew 1 Total Unit Cost: $1,740/day
Crew 2	
(2) Operators	Unit Cost: $1,440/day
Slung Level C	Unit Cost: $5/day
(2) Forklifts	Unit Cost: $170/day
(5) Laborers	Unit Cost: $3,600/day
Slung Level C	Unit Cost: $15/day
(2) Scissor Manlifts	Unit Cost: $70/day
(2) Welders	Unit Cost: $1,440/day
Welding Rig	Unit Cost: No Cost
Crane	Unit Cost: No Cost
	Crew 2 Total Unit Cost: $6,740/day
Crew 3	
(2) Level B - Primary	Unit Cost: $1,440/day
Level B equipment	Unit Cost: $400/day
(2) Backhoes (w/hammers)	Unit Cost: $300/day
Cutting torches	Unit Cost: No Cost
Fork lift	Unit Cost: $85/day
(1) Level B - Backup	Unit Cost: $720/day
Level B equipment	Unit Cost: $200/day
(2) Level C - Decon	Unit Cost: $1,440/day
Level C equipment	Unit Cost: $150/day
	Crew 3 Total Unit Cost: $4,735/day
Crew 4	
(2) Level C - Primary	Unit Cost: $1,440/day
Level C equipment	Unit Cost: $150/day
(1) Level C - Backup	Unit Cost: $720/day
Level C equipment	Unit Cost: $75/day
(2) Level D - Decon	Unit Cost: $1,440/day
Level D equipment	Unit Cost: $10/day
	Crew 4 Total Unit Cost: $3,835/day
Crew 5	
(4) Operators	Unit Cost: $2,880/day
(2) Dump Truck	Unit Cost: $225/day
(2) Blackhoes	Unit Cost: $250/day
	Crew 5 Total Unit Cost: $3,355/day

DEMOLITION, INCINERATION, AND LANDFILL OPTION					TVA			TVA			TVA			TVA
	Est.	Mat'l/Equip	Small Tool/	Crew 1 - H&S Officer and Foremen			Crew 2 - General Labor			Crew 3 - Level B Activities			Crew 4 - Level C	
ACTIVITY	Duration (days)	Total Cost	Consum. (1% of labor)	Duration (days)	Billing Rate (per day)	Cost	Duration (days)	Billing Rate (per day)	Cost	Duration (days)	Billing Rate (per day)	Cost	Duration (days)	Billing Rate (per day)
MOBILIZATION	7			0	1740	0	7	6740	47180	0	4735	0	0	
SITE PREPARATION														
Clear and Grub														
Glove Boxes	4		270	2	1740	3480	4	6740	26960	0	4735	0	2	
Electrical Conduit	10		674	5	1740	8700	10	6740	67400	0	4735	0	0	
Old pit steel	14		944	10	1740	17400	14	6740	94360	0	4735	0	4	
Light Decontamination	2		135	1	1740	1740	2	6740	13480	0	4735	0	0	
Outer yard area	4		270	2	1740	3480	4	6740	26960	0	4735	0	0	
SECONDARY CONTAINMENT														
Sealing of 537 Work Area	14	7050	944	7	1740	12180	14	6740	94360	0	4735	0	2	
Installation of Entry Doors	3	6000	202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
Damper Installation	1	400	67	1	1740	1740	1	6740	6740	0	4735	0	0	
VENTILATION SYSTEM														
For Secondary Containment														
Structure	2	400	135	1	1740	1740	2	6740	13480	0	4735	0	0	
Fan	3	6500	202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
Near Loading Area														
Structure	2	400	135	1	1740	1740	2	6740	13480	0	4735	0	0	
Fan	3	6500	202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
CONCRETE CRUSHING AREA														
Unit	4	40000	270	2	1740	3480	4	6740	26960	0	4735	0	0	
Pad	1	1000	67	0.5	1740	870	1	6740	6740	0	4735	0	0	
Guards/Chute	2	500	135	1	1740	1740	2	6740	13480	0	4735	0	0	
INCINERATION UNIT														
Main Unit		1650000												
Rotary Kiln	5		337	2.5	1740	4350	5	6740	33700	0	4735	0	0	
Fume Combustion Chamber	2		135	1	1740	1740	2	6740	13480	0	4735	0	0	
Blowers	2		135	1	1740	1740	2	6740	13480	0	4735	0	0	
ID Fan	3		202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
Control System	4		270	1.5	1740	2610	4	6740	26960	0	4735	0	0	
Technical Support	3	10000	202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
System NG Piping	8	1600	539	4	1740	6960	8	6740	53920	0	4735	0	0	
Backup Burners (2)	2	10000	135	1	1740	1740	2	6740	13480	0	4735	0	0	
Backup ID Fan	2	15000	135	1	1740	1740	2	6740	13480	0	4735	0	0	
ADD'L SYSTEM COMPONENTS														
Concrete Pad	4	2800	270	1.5	1740	2610	4	6740	26960	0	4735	0	0	
Backup System														
Mixing Chamber	2	52000	135	1	1740	1740	2	6740	13480	0	4735	0	0	
Radiator + Base	4	59100	270	2	1740	3480	4	6740	26960	0	4735	0	0	
Carbon Unit	2	61000	135	1	1740	1740	2	6740	13480	0	4735	0	0	
Gas Trains (3)	4	62000	270	2	1740	3480	4	6740	26960	0	4735	0	0	
System Piping	60	56950	4044	40	1740	69600	60	6740	404400	0	4735	0	0	
Stack	2	10100	135	1	1740	1740	2	6740	13480	0	4735	0	0	
Compressors	4	5500	270	2	1740	3480	4	6740	26960	0	4735	0	0	
MCC	5	40400	337	4	1740	6960	5	6740	33700	0	4735	0	0	
UPS	3	28000	202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
Generators (2)	4	35000	270	2	1740	3480	4	6740	26960	0	4735	0	0	
Fuel For Generators	1	25000	67	0	1740	0	1	6740	6740	0	4735	0	0	
Fuel Storage Tank	3	2200	202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
Electrical Bulks	4	8500	270	2	1740	3480	4	6740	26960	0	4735	0	0	
Natural Gas	2	13300	135	0	1740	0	2	6740	13480	0	4735	0	0	
Site and Area Lighting	3	5000	202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
Misc. Site Materials and Equip.	5	8450	337	2.5	1740	4350	5	6740	33700	0	4735	0	0	
INSTRUMENTATION AND CONTROLS														
Control Trailer	4	2700	270	2	1740	3480	4	6740	26960	0	4735	0	0	
Control System	18	94300	1213	12	1740	20880	18	6740	121320	0	4735	0	0	
Instrumentation	30	193600	2022	20	1740	34800	30	6740	202200	0	4735	0	0	
Programming	60			60	1740	104400	0	6740	0	0	4735	0	0	
SYSTEM CHECKS AND CHALLENGES														
Testing of equipment	3		202	1.5	1740	2610	3	6740	20220	0	4735	0	0	
Operation Challenges	12		809	10	1740	17400	12	6740	80880	0	4735	0	0	
DEMOLITION														
Tanks	20		674	14	1740	24360	10	6740	67400	20	4735	94700	0	
Equipment and Supplies														
Concrete	36		1348	28	1740	48720	20	6740	134800	30	4735	142050	2	
Equipment and Supplies														
Soil	4		270	4	1740	6960	4	6740	26960	2	4735	9470	4	
Equipment and Supplies														
Sampling Operations	8		270	3	1740	5220	4	6740	26960	4	4735	18940	2	
Shoring Operations	8		202	7	1740	12180	3	6740	20220	6	4735	28410	4	
INCINERATION														
Tanks	7		472	7	1740	12180	7	6740	47180	0	4735	0	4	
Concrete	14		944	14	1740	24360	14	6740	94360	8	4735	37880	7	
Soil	3		202	3	1740	5220	3	6740	20220	0	4735	0	2	
Material Sampling	4		270	2	1740	3480	4	6740	26960	0	4735	0	0	
DAILY DECONTAMINATION														
Install Decon Line for Personnel	2	400	0	1	1740	1740	0	6740	0	0	4735	0	0	
Install Decon Area for Equipment	2	600	0	1	1740	1740	0	6740	0	0	4735	0	0	
Personnel Decon	40		0	14	1740	24360	0	6740	0	6	4735	28410	0.5	
Equipment Decon	12		0	3	1740	5220	0	6740	0	2	4735	9470	0.5	
Secure Site	60	200	0	5	1740	8700	0	6740	0	0	4735	0	2	
FINAL SAMPLING OPERATIONS	4		202	1.5	1740	2610	3	6740	20220	0	4735	0	1	
LANDFILL														
Loading	7		0	3.5	1740	6090	0	6740	0	0	4735	0	0	
Transportation	7		0	3.5	1740	6090	0	6740	0	0	4735	0	0	
Off-loading	7		0	3.5	1740	6090	0	6740	0	0	4735	0	0	
DEMOBILIZATION	7		0	0	1740	0	7	6740	47180	0	4735	0	0	
TOTALS	598	2520450	23657			595080			2460100			369330		

	TVA			TVA		
Crew 4 - Level C Activities			Crew 5 Landfilling Activities			
Duration (days)	Billing Rate (per day)	Cost	Duration (days)	Billing Rate (per day)	Cost	ACTIVITY
0	3835	0	0	3355	0	MOBILIZATION
						SITE PREPARATION
						Clear and Grub
2	3835	7670	0	3355	0	Glove Boxes
0	3835	0	0	3355	0	Electrical Conduit
4	3835	15340	0	3355	0	Old pit steel
0	3835	0	0	3355	0	Light Decontamination
0	3835	0	0	3355	0	Outer yard area
						SECONDARY CONTAINMENT
2	3835	7670	0	3355	0	Sealing of 537 Work Area
0	3835	0	0	3355	0	Installation of Entry Doors
0	3835	0	0	3355	0	Damper Installation
						VENTILATION SYSTEM
						For Secondary Containment
0	3835	0	0	3355	0	Structure
0	3835	0	0	3355	0	Fan
						Near Loading Area
0	3835	0	0	3355	0	Structure
0	3835	0	0	3355	0	Fan
						CONCRETE CRUSHING AREA
0	3835	0	0	3355	0	Unit
0	3835	0	0	3355	0	Pad
0	3835	0	0	3355	0	Guards/Chute
						INCINERATION UNIT
						Main Unit
0	3835	0	0	3355	0	Rotary Kiln
0	3835	0	0	3355	0	Fume Combustion Chamber
0	3835	0	0	3355	0	Blowers
0	3835	0	0	3355	0	ID Fan
0	3835	0	0	3355	0	Control System
0	3835	0	0	3355	0	
0	3835	0	0	3355	0	System NG Piping
0	3835	0	0	3355	0	Backup Burners
0	3835	0	0	3355	0	Backup ID Fan
						ADD'L SYSTEM COMPONENTS
0	3835	0	0	3355	0	Concrete Pad
						Backup System
0	3835	0	0	3355	0	Mixing Chamber
0	3835	0	0	3355	0	Radiator + Base
0	3835	0	0	3355	0	Carbon Unit
0	3835	0	0	3355	0	Gas Trains (3)
0	3835	0	0	3355	0	System Piping
0	3835	0	0	3355	0	Stack
0	3835	0	0	3355	0	Compressors
0	3835	0	0	3355	0	MCC
0	3835	0	0	3355	0	UPS
0	3835	0	0	3355	0	Generators (2)
0	3835	0	0	3355	0	Fuel For Generators
0	3835	0	0	3355	0	Fuel Storage Tank
0	3835	0	0	3355	0	Electrical Bulks
0	3835	0	0	3355	0	Natural Gas
0	3835	0	0	3355	0	Site and Area Lighting
0	3835	0	0	3355	0	Misc. Site Materials and Equip.
						INSTRUMENTATION AND CONTROLS
0	3835	0	0	3355	0	Conrol Trailer
0	3835	0	0	3355	0	Control System
0	3835	0	0	3355	0	Instrumentation
0	3835	0	0	3355	0	
						SYSTEM CHECKS AND CHALLENGES
0	3835	0	0	3355	0	
0	3835	0	0	3355	0	
						DEMOLITION
0	3835	0	0	3355	0	Tanks
						H&S Equipment and Supplies
2	3835	7670	0	3355	0	Concrete
						H&S Equipment and Supplies
4	3835	15340	0	3355	0	Soil
						H&S Equipment and Supplies
2	3835	7670	0	3355	0	
4	3835	15340	0	3355	0	
						INCINERATION
4	3835	15340	0	3355	0	Tanks
7	3835	26845	0	3355	0	Concrete
2	3835	7670	0	3355	0	Soil
0	3835	0	0	3355	0	
						DAILY DECONTAMINATION
0	3835	0	0	3355	0	Install Decon Line for Personnel
0	3835	0	0	3355	0	Install Decon Area for Equipment
0.5	3835	1917.5	0	3355	0	Personnel Decon
0.5	3835	1917.5	0	3355	0	Equipment Decon
2	3835	7670	0	3355	0	Secure Site
1	3835	3835	0	3355	0	
						LANDFILL
0	3835	0	7	3355	23485	Loading
0	3835	0	7	3355	23485	Transportation
0	3835	0	7	3355	23485	Off-loading
0	3835	0	0	3355	0	DEMOBILIZATION
		141895			70455	

TABLE 7.5

CONSTRUCTION AND EQUIPMENT COSTS

DEMOLITION, INCINERATION, AND LANDFILL OPTION
COST ESTIMATE
ROCKY MOUNTAIN ARSENAL
BUILDING 537 MUSTARD PIT

hazardous condition. Health and safety risks and disadvantages inherent to the DIL alternative are difficult to quantify and estimate. Cost impacts due to additional work required to overcome safety risks are attributable to the following factors:

The loss of productivity due to workers suited in Personnel Protective Equipment

The extra care for demolition operations in the close quarters

Protection of the building structure during demolition

Protection against atmospheric release

The cost of these items is difficult to quantify, and justify the inclusion of a 10 percent contingency in the estimate.

In comparison, the HGDS adjusted cost ($5.3 million) is approximately half of the estimated $10.4 million cost for the only approved alternative, the DIL option. From this analysis, it is concluded that the HGDS remediation method is more economical. In addition, the Hot Gas technology is projected to be a safer operation, and.does not require.the amount of non-standard construction methods as the DIL option.

8.0 LESSONS LEARNED AND RECOMMENDATIONS

8.1 GENERAL

The Hot Gas technology should be considered for decontamination and decommissioning projects where chemical agent or volatile organics are the contaminants of concern. Before widespread application of the Hot Gas technology, additional field demonstrations may be advisable. These would be helpful to fine tune and advance the Hot Gas technology, taking advantage of the lessons learned at Rocky Mountain Arsenal. Also, bench tests, pilot tests and field demonstrations are required for future Hot Gas projects which are directed at contaminants other than mustard agent, such as nerve agent, pesticides, herbicides, or solvents.

The existence of primary breakdown products of mustard agent (oxathiane and dithiane) in the process equipment, stack exhaust, and inside and outside of secondary containment was noted during operation and shutdown of the HGDS. The effectiveness of the HGDS heat soak (350 °F for 24 hours) and fume burner destruction (2,000 °F for 2 seconds) when applied to these byproducts was not part of the scope of this project. The health effects of these substances are not well known or documented. However, their presence and potential hazard cannot be overlooked in the future. Oxathiane and dithiane concentrations were reduced but not eliminated in both the mustard pit and in the exhaust gases. Future projects may require the total destruction of both mustard agent and byproducts. The suitability and applicability of the Hot Gas process for destruction of these byproducts should be examined.

More detailed study of toxicological and health effects of mustard by-products, including oxathiane, dithiane, and other unnamed substances, should be undertaken. The presence of these materials around the site and in the process gas was a constant source of concern during operation.

8.2 PROCESS EQUIPMENT

8.2.1 General

Specific recommendations regarding the process and future projects are as follows.

Existing process equipment from the HGDS at Rocky Mountain Arsenal was designed and specified for standard lifetime and reliability, rather than short lifetime or temporary service. Consequently, the HGDS equipment can be reused on future projects.

The HGDS and process equipment were designed around operation during winter conditions for the purpose of safety containment of mustard in the vicinity of the field demonstration. This criterion was extended to the system and unit process equipment which were specified with a maximum ambient operating temperature of 70 °F. This limitation was approached on numerous occasions during the field demonstration in March 1994, which was an unusually warm month. Specifications for unit process equipment and systems operations should allow for year-round operation of the HGDS. Each piece of equipment should be specified to meet performance standards beyond those expected in normal operation, including flow and temperature. Establishment of design criteria which are temperature restrictive does not serve the purpose of operational flexibility. While winter operation for safety containment is ideal, it is not practical to assume that average weather will occur. The cost of an 8-month time delay over the spring, summer, and fall months (if the project runs late) does not warrant the restrictions placed on the design due to temperature limitations.

The design of the Hot Gas system and process components must emphasize startup and cooldown conditions as primary performance criteria, in addition to normal process operation. Startup and cooldown present an entirely different set of operating conditions for required flow rates, temperatures, pressures, instrument ranges, and system demands. The system and components must be capable of withstanding the wide range of operating conditions present during these phases.

Cold (startup) operating conditions should be particularly emphasized in the design criteria for equipment. This allows for increased operating flexibility and ease of component checkout and system startup.

System design should maximize capabilities for cooldown of the target area after the heat soak is complete. Accommodations for injection of large amounts of ambient air should be made to accelerate cooling, to promote operational flexibility, and to reduce operations cost. Provision should be made for cooling air to be drawn into the system without being drawn through the main burner. For example, the recirculation system could be fitted with an inlet nozzle for outside air injection into the pit. During cooldown, increased flow through the pit would promote increased cooling effectiveness and decreased cooldown time and cost.

Future designs should retain the level of redundancy of the field demonstration of the HGDS for operational and safety reasons.

On future projects, a Hot Gas system can be designed to process combustible materials as well as decontaminating non-combustible materials, as long as structural integrity of the structure is not jeopardized.

8.2.2 Fume Burner

Fume burner operating criteria (temperature and residence time) should be set in terms of minimums and maximums, to permit realistic performance objectives for operators to achieve. Establishment of precise operational criteria is unreasonable when numerous variables affect performance. An operating range for temperature and residence time is the only practical approach to performance objectives.

In order to keep the fume burner at its design criteria target, the HGDS system became limited in terms of flow throughput by the capacity of the fume burner to treat exhaust. At times during heatup and particularly during cooldown, it was desirable to increase the system throughput, but this was not possible due to the fume burner sizing. During cooldown, increased flow through the pit would have increased cooling effectiveness and decreased cooldown time. It is recommended that a large factor of safety be used when sizing the fume burner on future projects, to allow operators more freedom to increase flow through the fume burner.

It was determined that the Backup Mode had significantly more capacity for cooldown capability than the Normal Mode, since the carbon unit could process more throughput than the fume burner without loss of effectiveness.

The backup treatment system (carbon filter and radiator) may provide a suitable alternative to the fume burner unit, if thermal exhaust treatment technologies are not desirable on future projects.

8.2.3 Mixing Chamber

Auxiliary ambient cooling air (in addition to secondary containment air) injected into the mixing chamber strongly affected all aspects of the HGDS process. Restricted by temperature limitations of the fabric isolation joints at the ID fans, control and balancing of the fume burner operating criteria, exhaust temperature, and system pressure was difficult. Auxiliary ambient air was increased to cool the exhaust gasses, which caused less negative pressure in the containment area and process. Adjustments in the negative pressures in primary and secondary containment ultimately affected the control of exhaust gas temperatures.

8.2.4 Radiator

Specifications for future radiator procurements should require standards and pressure testing for leaks, and documentation of such testing. A certified welding inspection conducted at the factory should be required in the purchase specifications. Operational procedures or design features should be implemented to dry condensate from the radiator after it is operated.

If placed in future use, the existing radiator may be fitted with a containment system or condensate control system to control condensate leakage. Economical repair of the existing radiator may not be feasible, because the leaks are apparently located inside of the radiator structure.

8.2.5 Carbon Filter

As presently configured, the system relies on excess carbon media capacity to offset the possibility of media exhaustion and breakthrough. Multiple carbon filter units were considered in the concept design, but not included due to cost. If unanticipated loading occurs, the system as presently configured is shut down to change filter medium. Consideration should be made to allow bypass of the carbon filter in the event that replacement of filter medium is required. For example, the secondary containment ventilation air can be re-routed to the fume burner during the carbon replacement operation.

The carbon filter was used to directly treat the ventilation air from the secondary containment. This design concept was theoretically sound based on winter ambient conditions. However, in practice, above normal ambient temperatures and heat emanating from the pit combined to drive temperatures in secondary containment beyond acceptable levels. A simple process revision would have mitigated this situation and increased system flexibility. The ventilation air from secondary containment should have been routed through the radiator to cool it to acceptable levels for the carbon filter.

8.2.6 Recirculation Fan

The recirculation fan (or any fans on the process train) should not have operational limits for minimum temperatures, as is the case with the 400 °F minimum for the recirculation fan. This restricts the capability to cold test the fan during component checkout, and inhibits operational flexibility during heatup and cooldown. A greater operating range is desirable.

If the existing recirculation fan is re-used on another project, the noise problem must be investigated and the fan repaired.

8.2.7 Induced Draft Fans

Due to the inherent variability of an open system, certain flow rates and pressures varied from the design values during operation. It is advisable to oversize the ID fans to provide additional operating flexibility.

It is necessary to have control dampers that are effective at very low flow rates. If such control dampers cannot be provided, high performance butterfly valves with straightening vanes could be an acceptable design approach. Equipping the fans with adjustable frequency drives may serve the same purpose and promote more flexible operation and easier system control.

The temperature limitation of the materials of construction at the ID fans and fabric expansion joints was a limiting condition for operation of the HGDS. As the control system is currently configured, a temperature gauge located at mid-height on the stack was used to monitor the temperature at the fans. This temperature was physically read on the operator's hourly rounds. The height of the gauge on the stack created a low accuracy reading (especially in darkness). Considering the critical nature of this data, a continuous temperature monitor at the fan discharge is warranted.

8.2.8 Instrumentation

Process Instrumentation

Future projects should be fitted with direct reading instruments, such as thermometers and pitot tubes, for all critical remote reading instruments to allow calibration/comparison of information in the case of questionable data, and for backup in the event of failure of remote reading instruments. Use of reliable and proven instrumentation that can be field-calibrated and checked during operation is recommended. Additional direct measurement of pressure and temperature at several process locations would be helpful. Examples of desirable locations would be the fume burner inlet, mixing chamber discharge, the inlets of the ID fans, and the stack discharge.

For future Hot Gas projects, the effects of heat and vibration on the performance and durability of process instruments should be emphasized in the design. The wide variation of operational requirements for winter ambient temperatures (including cold starts), and processing exhaust gasses at temperatures ranging from 100 °F to 2,000 °F is very demanding. The projected system lifetime of future projects could influence the choice of equipment. Sensitive instruments should not be located anywhere in the vicinity of the main burner discharge even when apparently upstream in the recirculation loop.

Conduction of heat along the duct in this area will cause the temperature of the duct to far exceed the process gas temperature, and potentially damage the instruments.

As an alternative to the mass flow meters used, it is advisable to use more durable instruments, such as a multi-hole Pitot type device (Annubar). The signal from this device can be converted to mass flow by the PLC using temperature and pressure signals from the same location. Also, flow meters should be capable of field calibration, to allow for adjustment to minor changes in the system.

Precise measurement of clearance of sensing elements within system piping should be undertaken and field-verified before installation. Instrument technicians should exercise the utmost care and sensitivity during installation of instruments. Any increased resistance during installation should be cause for concern and caution.

All sources of inlet air into the HGDS and structure should be closely controlled and measured. For example, the gravity damper in the secondary containment should have a motorized control damper and flow measurement device. Also, the secondary containment ventilation air pipe should be fitted with a control valve.

A remotely operated control valve on the cold bypass test duct would allow additional flexibility during startup. The objective is to first ramp up the fume burner operating temperature, and then bring the pit on-line. A control valve with remote operation would replace the spectacle blind in the hot gas inlet manifold for automatic operation.

In order to simulate air in-leakage to the system, test bypass ducts on future projects should be provided with nozzles to the atmosphere, which are fitted with valves to throttle or close the nozzle.

The temperature of the fume burner was monitored by two thermocouples placed into the fume burner chamber. The thermocouples were placed into metal wells in the chamber. The wells were in direct sight of the flames which would radiate heat to these wells. The wells would also conduct heat away and radiate heat to the surrounding walls. These major factors impact the accuracy of the temperature reading of the fume burner. The true gas temperature can be determined by one of three approaches:

- Corrections to the temperature readings can be done by adjusting for the errors using equations,
- Using a system which reduces the errors to a small percentage, or
- Using a suction pyrometer.

The suction pyrometer measures the gas temperature under known conditions. The suction pyrometer shields the thermocouple from radiation and pulls a sample of the gas stream across the thermocouple at sufficient velocity to reduce errors. This provides an accurate reading of the gas temperature. For future operations, a suction pyrometer should be used in situations where accurate high gas temperature (greater than 1,600 °F) readings are needed. For control, thermocouples in wells can continue to be used.

Cabinets for storage and organization of loose equipment, instruments and spare parts are also advisable on future projects.

Monitoring Instrumentation

Ambient work area agent monitoring with remote indication and alarms should be provided for all areas close to the target area which are subject to frequent inspections or habitation by workers.

Monitoring devices, such as Minicams, should be calibrated to monitor and measure the primary decomposition products of mustard agent (oxathiane and dithiane). Plant operators should be able to confirm and quantify the presence of both mustard agent and the primary decomposition products. DAAMS tube samples, or other sampling methods, can be used to provide quality control of the monitoring devices.

Testing and calibration of monitoring instruments should include the complete sampling and instrument system. The complete data collection system should be challenged for accuracy prior to startup. The monitoring instrument should not be isolated off-line for calibration, so that problems in the sampling lines and system (such as blockage or pressure backflow) do not go undetected.

The Minicams should be placed on-line such that calibration checks can be conducted without disrupting the normal operation of the Minicam. For example, challenging operations should not isolate the sampling system from any physical operating conditions at the time of challenge.

In the future, the Minicam dilution boxes should be modified so that the injection port for challenge material is upstream of the dilution box and before the dilution air is mixed with the sample in the dilution box. This will allow the dilution box operation to be checked during operation.

A quantifiable means of determining the amount of mustard agent that was volatilized should be provided. Monitoring of SO_2, HCl, Oxathiane, or Dithiane may be indicators of the levels of mustard agent volatilized during decontamination operations.

A suction pyrometer should be used for critical gas temperature measurements where radiant and conductive heat transfer factors impact the accuracy of a thermocouple (e.g., in the fume burner). Inaccurate temperature measurements can affect computer calculations such as residence time, temperature gradients and trends, and impact the design system performance.

Data Acquisition System

In the future it would be helpful to alarm the DAS for data stoppages. Also a modem would be advisable, so that data could be transmitted from the field to an office for analysis on another PC.

The DAS should be equipped with audible alarms when problems occur. Several times, problems were overlooked due to the screen-saving function of

Windows®. A continual beep instead of one beep and a brief message would be helpful in calling attention to the problem.

8.2.9 Mechanical

The spiral-wound pipe used for process ductwork was found to have excessive pin-holes, poor quality welds, and was out-of-round. The use of standard pipe is advisable on future projects.

8.2.10 Electrical

The Motor Control Center control circuits for the motor starter should be powered from the UPS in future operations. This prevents the starters from dropping out during power transfer switch operation. This change was incorporated during the initial testing phase and before system operation.

8.3 OPERATIONS

Operating procedures which are prepared prior to system startup cannot anticipate all possible operating scenarios. Operating procedures should be prepared to provide flexibility during operation. Supplementary operating procedures should be used to amend or revise operating procedures when appropriate.

A target temperature to be achieved in the structure to permit shutdown of the HGDS must be a realistic standard. The use of ambient temperature in the target structure as the criterion for the shutdown of the HGDS is unrealistic. The time and expense of full system operation to meet this criterion is prohibitive. Temperature standards for shutdown of the HGDS on future projects should be set so that they are achievable in a reasonable amount of time. A criterion based on the limit for human exposure to burns (commonly used at 100 °F) is reasonable.

The intentionally slow heatup rate of the pit was a direct result of the structural load-bearing nature of the east pit wall. A faster heatup period is technically feasible, if structural integrity or damage is not an issue. If future sites for Hot Gas technology are selected where the target area is not load-bearing, or damage to the concrete is not an issue, much faster heatup can be achieved to reduce operations time and cost.

In addition, areas with high soil moisture content or high water table will experience considerably longer heatup operations time and higher energy cost to overcome the heat of vaporization of the moisture.

8.3.1 Sampling and Analysis

Concrete Core Samples

An approach to check the total residual mustard breakdown products (as sulfur) in concrete core samples, would be to take a known amount of the crushed concrete and place it in a tube furnace. A sweep gas could be passed over the concrete during heat up to about 2,400 °F to collect the sulfur released during heat-up. The gas stream could be bubbled through a hydrogen peroxide solution to collect all sulfur released from the concrete. The analysis of the solution for sulfur would provide an indication of the residual sulfur contained in the concrete. This type of test would provide an indication of the total sulfur content before and after a test. This test assumes that all the sulfur originated from mustard. The same type of test could be done for phosphorus compounds.

Placement of Sampling Lines

In future operations the sampling lines need to be further away from heat for extended service life and ease of replacement. The placement should be out of the traffic flow but convenient for operation.

Wet Chemistry Methods

Where possible, it would be desirable to have a quick wet chemistry and/or colorimetric method to perform analysis for various compounds instead of waiting for lab results or turn-around. This is a wish list type item that may not be practical for many applications but would provide a quick indication of results or what is going on during a test. The accuracy may not be precise but it will provide an indication.

Portable Computer with Modem

A portable computer with a modem would allow the transfer of data back from the test site to an office for analysis. Another option would be to equip the data acquisition system with data transfer capabilities.

8.4 STRUCTURAL

A complete structural inspection of the building before and after future field demonstrations of the Hot Gas process would provide critical information on the potential reuse of facilities. In the case of Building 537 at Rocky Mountain Arsenal, a post-test structural inspection and laboratory analysis would be useful to determine if any structural damage occurred. This information would be invaluable for future projects to determine future allowable maximum temperatures, maximum temperature gradients for cross-sections, and maximum heatup rates.

The possibility of structural damage due to foundation settlement should be anticipated. The evaporation of ground water from below the foundation will accelerate consolidation of the soils, and may promote structural damage. Soil consolidation due to thermal heating may be a significant design factor. Detailed geotechnical and structural analysis of the surrounding soils and structure is advisable for future projects. The services of a geotechnical engineer to investigate the possibility of soil consolidation may be required. The geotechnical engineer could also assist the structural engineer by designing new foundations if required. The structural engineer should anticipate and calculate any areas where excessive movements or thermal expansion may occur during the decontamination process.

The risk of fire or heat damage to the structure should be investigated in the early portions of the design phase. Each process area (such as primary containments or secondary containment) may require special attention. Older structures are at the greatest risk for damage.

8.4.1 Primary Containment

The walls of the mustard pit were not true and straight when constructed, and undulate along their length. During construction, each plenum support structure was custom-fit to the area where placed. This was a costly, time-consuming, and unexpected occurrence. Field surveys inside the mustard pit were not conducted during the design phase due to safety considerations. A transit survey prior to the design would have reduced the impact of these field changes.

On future projects, there is potential for combination of the primary containment and plenum into a single structure, if the geometrics of the target area permit. A flat horizontal floor surface is one example of a structure which the primary containment could serve a dual function as plenum.

8.4.2 Secondary Containment

The porous cinder block and cracks, penetrations, doors, and openings in the building walls created breaches in secondary containment, which were tedious and costly to seal. These were sealed during construction with grout, concrete block, and high temperature tape. Heatup of the building caused further cracking in the walls, increasing in-leakage during heatup. These cracks and leaks caused negative pressure in secondary containment to be less negative than desired.

Another method for sealing should be considered, such as more extensive use of membrane fabric. This may be quicker, cheaper, and more effective. A light membrane material or plastic film should be considered for sealing secondary containment, for ease of construction.

Both temperature control of the fume burner and pressure control of secondary containment were adversely affected by the high porosity of the building walls, and an unexpected amount of air leakage into secondary containment.

Future projects should not use primary containment walls to also act as secondary containment walls. A small portion of the east wall of the Building

537 was utilized as both primary and secondary wall. Minor cracking during the operation of the field demonstration reduced the effectiveness of this wall to provide secondary containment. The secondary containment could have been constructed to enclose this area at the eastern edge of Building 537, in the corridor between the buildings. This area was the source of constant agent monitoring and safety concern, due to visible off-gases of heat and steam from the ground at the edge of the building. Capture of off-gases and routing through the secondary containment and carbon filter treatment system would have reduced the safety concern of workers entering this area.

When ambient temperatures are above 70 °F, secondary containment will require supplemental cooling in order to meet the operational requirements of the carbon filter. Ventilation air from secondary containment to the carbon filter approached or exceeded the maximum design temperature of 130 °F for the carbon media on many occasions during the HGDS test. However, additional cooling air passing through secondary containment must not result in a lower negative pressure in secondary containment. Consequently, larger ID fans or a better-sealed secondary containment system may be required to maintain negative design pressures.

The use of visual monitoring and lighting equipment within the containment areas would allow for inspection of the integrity of the load-bearing walls and secondary containment.

8.5 CIVIL DESIGN

Antiquated drawings for government facilities should not be assumed to reflect as-built conditions. It is reasonable to say that as-built construction conditions and building modifications over the years may not have been documented. The accuracy of antiquated plans should be confirmed through the use of field measurements, physical observation, surveys and photographs. A transit survey is recommended to verify existing conditions (including exclusion zones) before the outset of design. The transit survey, site walk, and historical use review should be conducted before construction drawings are produced. Survey benchmarks should be established at an early stage in the site investigation. The site contamination assessment should identify contaminated areas and contaminants outside of the target area, for the placement of process equipment and support facilities, and location of containment structures.

For future field demonstrations or full-scale pilot tests, a site that is not subject to widespread contamination is more appropriate to document the effectiveness of a process. The difficulties in controlling and treating contamination outside the test area at this site were formidable. The input heat cannot necessarily be controlled at the edge of the target contaminated areas, and accommodation must be made for fugitive emissions outside the target area. During operation of the HGDS, the levels of contamination in the secondary containment and outside the building were a safety concern, and were a distraction from the test objective. This was particularly the case during cooldown, when high levels of contaminant byproducts were detected.

The negative pressure feature of the system was intended to contain and draw inward those contaminants at the edge or just outside the target area. This occurrence may tend to bias results, when contaminants (unquantified, unplanned, and possibly unknown) from outside the target area are drawn into the test area and system. This bias may particularly occur during cooldown, when contaminants may be drawn inward into the target area and condense there. However, this phenomenon was not quantified or observed during this field demonstration. Ideally for field demonstrations, the site and system design should ensure that the test area is isolated from outside sources of contamination.

8.6 PROCUREMENT

For procurement under the Federal Acquisition Regulation requirements for low bid, a very high level of bid evaluation and acceptance should be exercised. During the procurement process for this project, low bid vendors furnished bids which met design criteria on paper. It was difficult if not impossible to foresee field and performance problems at this stage. Some higher level of bid requirements, such as references for identical equipment or shop drawings submitted with the bid, may have alleviated some of these problems. Vendor qualifications and experience should be carefully screened to ensure that they are experienced with the particular size and type of equipment required. Less qualified vendors should be eliminated. Several references for similar equipment should be required from vendors and references should be checked. Fail-safe engineering should be implemented whenever possible.

A qualified representative of the owner should witness critical performance tests for process equipment at the factory, inspect equipment, and review and accept test and inspection documentation. Receipt of shop drawings and factory inspection reports for process equipment should be mandatory before equipment is accepted at the job site. Procurement documentation (performance test reports and inspection reports) must be closely monitored for timeliness and reviewed for conformance to the specifications. Job site personnel should not have to accept "as-is" equipment.

Critical process systems and safety systems on hazardous projects should be purchased as sole source when appropriate, using quality and demonstrated experience as vendor selection criteria.

Strict adherence to the low bid procurement rules invites safety risk, and ultimately is more expensive when the cost of repairs and delays is factored into the overall project expense. Research and development (R&D) projects for hazardous applications can be negatively impacted by the effects of poor quality purchases which can result from the low bid procurement process. Future uses of innovative technologies can be adversely affected by biasing of results in R&D projects.

If space for process equipment is constrained, envelope and footprint restrictions must be clearly stated in the procurement documents, and strictly adhered to during vendor selection. Non-conforming bids should be disallowed for this reason alone.

Extra caution should be exercised during procurement of rental equipment, especially for critical systems. The combination of low bid procurement policy and use of rental equipment increases the potential for poor quality used equipment. The cost of schedule delays, idle personnel, and repair and maintenance of used rental equipment during testing and startup can outweigh the cost savings of the low bid. This was experienced with the rental Uninterruptible Power Supply (used) and Instrument Air Supply (new), which caused numerous delays and contractor repair problems.

9.0 CONCLUSIONS/APPLICABILITY

9.1 CONCLUSIONS

The Field Demonstration of the Hot Gas Decontamination System successfully proved that the Hot Gas technology is capable of decontaminating concrete and steel structures which have been operationally contaminated by mustard agent. The field demonstration met the functional requirements for complete volatization and destruction of the mustard agent in the concrete pit, and destruction of the mustard agent in the process exhaust gas.

The Hot Gas process can be effectively applied to operationally contaminated structures in a manner that protects worker and public health and safety, and promotes environmental protection. The secondary containment, primary containment, and negative pressure system proved effective in controlling volatilized off-gases from the process.

The cost of the field demonstration of the HGDS, from design through operation, was $5.9 million. An adjusted cost, which subtracts costs incurred due to project delays, was $5.3 million, and is considered the real cost of the project. A cost comparison to the only currently approved alternative technology (demolish and incinerate) indicated that the cost of the Hot Gas process is approximately half of the estimated $10.4 million cost of this alternative. In addition, the Hot Gas technology is projected to be a safer operation, and does not require the amount of non-standard construction methods as the alternate technology.

Core sample data shows that the design criteria for heat soak of concrete in the mustard pit (350 °F for 24 hours) was sufficient to volatilize and destroy mustard agent impregnated in the concrete. Also, levels of mustard by-products (oxathiane and dithiane) were reduced in the concrete.

During operation, the fume burner criteria of 2,000 °F for 2 seconds was sufficient to destroy mustard agent in the process exhaust. Several excursions below the 2-second residence time during operation indicate that a lower residence time may be sufficient to destroy the agent.

The number and location of thermocouples in the pit successfully provided real-time monitoring of the pit temperature at all times during the field demonstration. The control of heat input and distribution to the pit was satisfactory using the real-time data output from the thermocouples. The thermocouples proved to be durable and reliable.

The backup treatment system (carbon filter and radiator) provided effective treatment units for removing mustard contaminants from the process gas and secondary containment ventilation air.

The process redundancies designed into the HGDS were sufficient to support a safe and successful project. The process control and monitoring system provided adequate controls, automatic operations and safety response, with alarms to safely and efficiently operate the HGDS.

The HGDS is very flexible to operate, with a great number of process variables which are subject to control. Temperatures, flow rates, residence times, and equipment can be adjusted to meet the requirements of the process and contaminant. Heat-soak temperatures and exposure times can be readily controlled.

An advantage of the Hot Gas technology is that the process equipment and instrumentation used is generally off-the-shelf equipment that can be supplied by numerous vendors. No special equipment or design limitations inhibit the applicability of this technology. Some improvements to the specific details of process equipment and instrumentation can be implemented on future projects.

The controlled heatup, operation and cooldown of the HGDS diminished the potential for damage to the structural integrity of Building 537. No structural damage to the pit or building has been observed (after partial inspection), other than superficial cracking which was anticipated. From a structural perspective, a building that has undergone the Hot Gas process has potential for reuse or release from government control.

9.2 APPLICABILITY

The Hot Gas Decontamination System has been proven effective to decontaminate concrete and steel structures contaminated with mustard agent. Similar systems were demonstrated at Cornhusker, Nebraska and Hawthorne, Nevada, by USATHAMA (now USAEC) to decontaminate structures contaminated with explosives.

In addition to mustard agent and explosives, the Hot Gas technology has potential for use in decontaminating structures contaminated with a wide range of substances, including other types of chemical warfare agent (GB and VX), solvents, pesticides, herbicides, and other types of volatile organic substances. Additional bench-scale and pilot tests, and field demonstrations on these substances are required to determine the design criteria and effectiveness of the process in each case.

Hot Gas technology is effective as a decontamination technique on a wide variety of target media. It is applicable to decontamination of concrete and steel structures, process equipment and piping, and soil, and can be utilized in a production decontamination capacity. At a large post, a central decontamination facility using Hot Gas technology may be feasible to treat contaminated equipment, parts, and piping from multiple sites.

Each potential application of the technology should undergo an evaluation of the engineering feasibility and process constraints before it is used. The process is appropriate any time that cost and safety are primary criteria for the project.

A great advantage of the Hot Gas technology is that contact with the contaminant during construction and operation is minimized. The health and safety benefits of this advantage alone broaden the applicability of this technology. When new standards for decontamination ("5A" versus "5X") are finalized by the Army, the Hot Gas technology is potentially the basis of achieving those standards.